The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
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The Journal of Bone and Joint Surgery*

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TABLE OF CONTENTS

October 1956

PAGE

Prognosis in Dislocations of the Shoulder.
By *Carter Rodd Rowe, M.D.*, Boston, Massachusetts 957

Recurrent Ulnar-Nerve Dislocation at the Elbow.
By *Harold M. Childress, M.D.*, Jamestown, New York 978

Chronic Neurological Sequelae of Acute Trauma to the Spine and Spinal Cord. Part I. The Significance of the Acute-Flexion or "Tear-Drop" Fracture-Dislocation of the Cervical Spine.
By *Richard C. Schneider, M.D.*, and *Edgar A. Kahn, M.D.*, Ann Arbor, Michigan 985

Lengths of the Growing Foot.
By *Marie M. Blais, A.B.; William T. Green, M.D.*; and *Margaret Anderson, M.S. in P.H.*, Boston, Massachusetts 998

Fractures of the Tibial Condyle. A Clinical and Experimental Study.
By *Mason Hohl, M.D.*, and *J. Vernon Luck, M.D.*, Los Angeles, California 1001

Providing Automatic Grasp by Flexor Tenodesis.
By *James N. Wilson, M.D.*, Los Angeles, California 1019

Chondrosarcoma, A Surgical and Pathological Problem. Review of 212 Cases.
By *David C. Dahlin, M.D.*, and *Edward D. Henderson, M.D.*, Rochester, Minnesota 1025

Periodic Benign Synovitis. Idiopathic Intermittent Hydrarthrosis.
By *Alan D. Weiner, M.D.*, and *Ralph K. Ghormley, M.D.*, Rochester, Minnesota 1039

The Effects of Pressure on Epiphyseal Growth. The Mechanism of Plasticity of Growing Bone.
By *Alvin M. Arkin, M.D.*, and *Jacob F. Katz, M.D.*, New York, N. Y. 1056

The Effect of Staples and Longitudinal Wires on Epiphyseal Growth. An Experimental Study.
By *Robert S. Siffert, M.D.*, New York, N. Y. 1077

A Critical Evaluation of a Method of Epiphyseal Stimulation.
By *Earnest B. Carpenter, M.D.*, and *James B. Dalton, Jr., M.D.*, Richmond, Virginia 1089

Experimental Studies on Epiphyseal Stimulation.
By *C. Laird Wilson, M.D., F.R.C.S.(C)*, and *Edward C. Percy, M.D.*, Montreal, Quebec, Canada 1096

The Arterial Supply of the Adult Humerus.
By *P. G. Laing, M.D., F.R.C.S.(Eng.)*, Lancaster, New Brunswick, Canada 1105

(Continued on page 3)

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TABLE OF CONTENTS

(Continued from page 1)

PAGE

Ischiofemoral Arthrodesis of the Hip.
By *James B. Jones, M.D.; Arthur J. Driscoll, Jr., M.D.;* and *Halford Hallock, M.D.,* New York, N. Y. 1117

The Alveolar Soft-Part Sarcoma.
By *Arthur H. Stein, Jr., M.D.,* St. Louis, Missouri 1126

Congenital Heart Disease and Scoliosis.
By *Walter D. Wright, M.D.,* and *John J. Niebauer, M.D.,* San Francisco, California 1131

Two Unusual Dislocations at the Wrist.
By *Harold Seidenstein, M.D.,* Bronx, New York 1137

Spondyloschisis Following Spine Fusion.
By *Carl E. Anderson, M.D.,* Santa Rosa, California 1142

Hemipelvectomy: Surgical Technique.
By *Sam W. Banks, M.D.,* and *Sherman Coleman, M.D.,* Chicago, Illinois 1147

Boat-Nail Fixation of Tendons and Ligaments to Cancellous Bone.
By *Lieutenant Colonel Robert W. Augustine; Captain William R. MacAusland;* and *Lieutenant Willard F. Greenwald,* Medical Corps, United States Air Force 1156

A Bandsaw for Cutting Thin Tissue Sections.
By *Vannevar Bush, D. Eng.,* Washington, D. C. 1159

Simple Device for Constant, Slow Instillation of Small Quantities of Fluid.
By *Lieutenant W. Stanford Foultz,* Medical Corps, United States Naval Reserve 1163

The Role of the American College of Surgeons in the Treatment of Fractures.
By *W. L. Estes, Jr., M.D.,* Bethlehem, Pennsylvania 1165

Proceedings:
The American Orthopaedic Association 1168

The Evolution of Physiological Concepts in Bone Surgery. [Presidential Address.]
By *Paul C. Colonna, M.D.,* Philadelphia, Pennsylvania 1169

Virginia State Orthopaedic Society 1175

Ohio Orthopaedic Society 1176

Northeast Orthopaedic Club 1179

Texas Orthopaedic Association 1179

News Notes 1181

Book Reviews 1182

List of Advertisers ..... Adv. 56

Addresses of Contributors ..... Cover III

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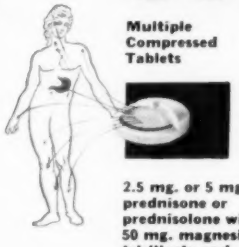

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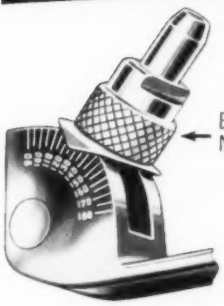

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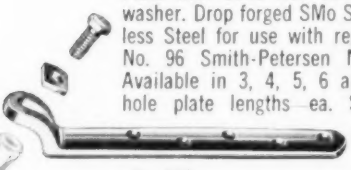

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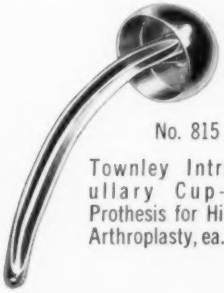

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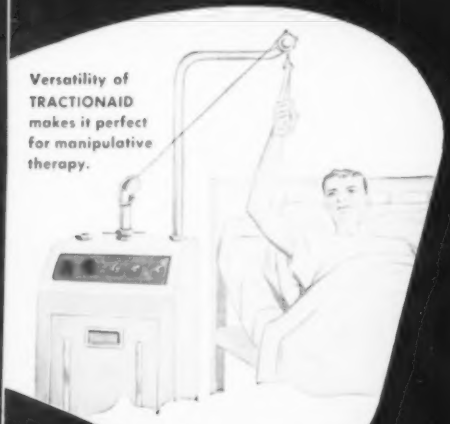

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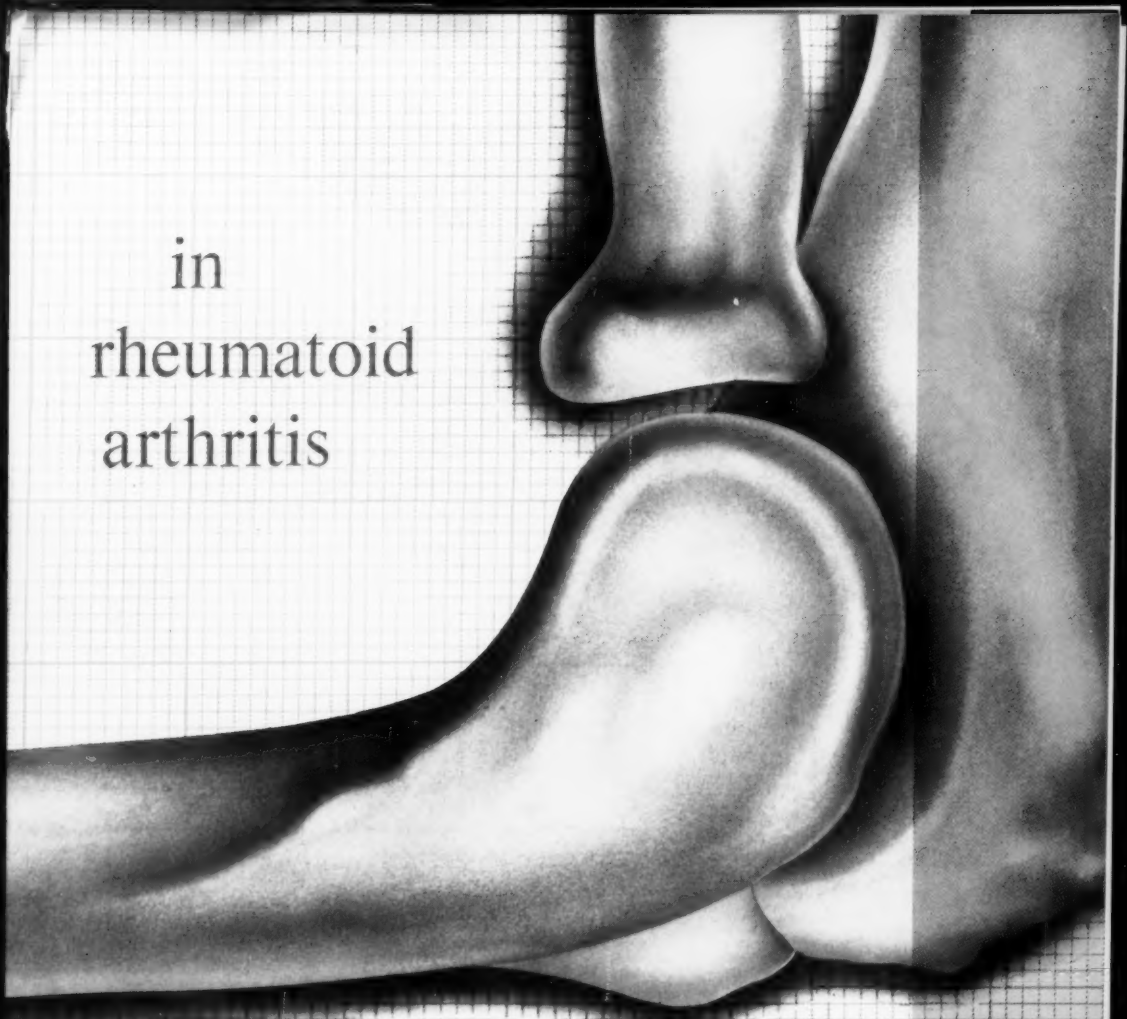

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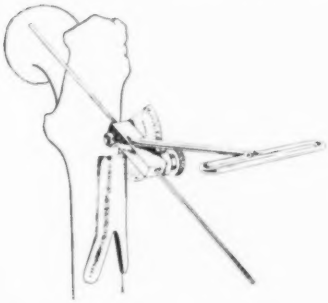

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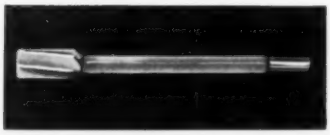

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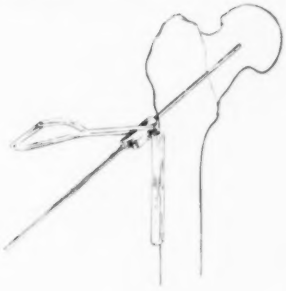

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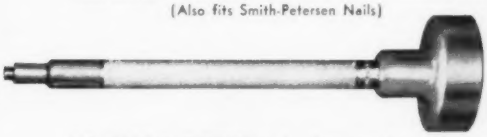
NO. 381D DRIVER, stainless .....**$ 7.00**

(Also fits Smith-Petersen Nails)



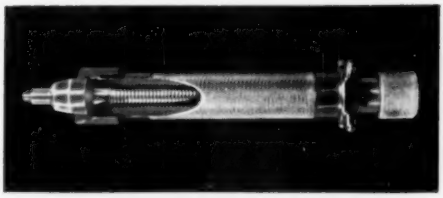
NO. 381DK DRIVER with Aluminum hand driving knob, stainless.....**$10.00**

NO.106A GUIDE PIN, stainless

$ .90 each .....**$9.50** doz.

NO. 106B GUIDE PIN, Calibrated, stainless

$1.25 each.....**$14.00** doz.



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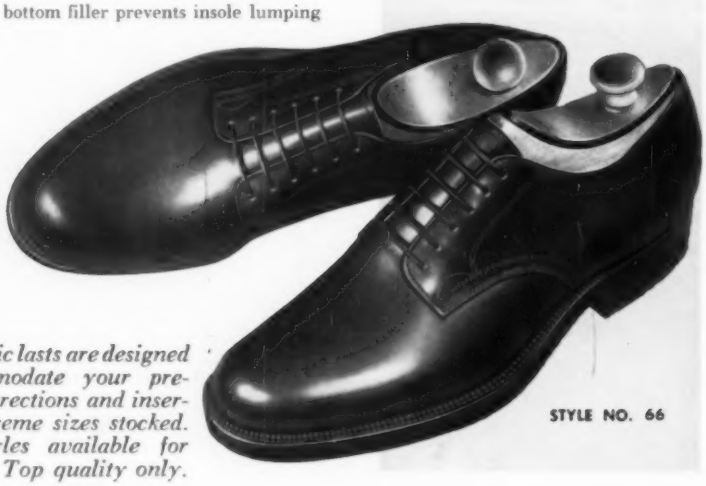

STYLE NO. 66

Alden-Pedic lasts are designed to accommodate your prescribed corrections and insertions. Extreme sizes stocked. Many styles available for men, boys. Top quality only.

Alden-Pedic lasts and shoes have been scientifically designed and tested to accommodate specific and general degrees of foot disabilities. To fit the foot shape and accommodate the prescribed corrections is the crux of our program. Doctors who become familiar with the functional merit of this program will be glad to prescribe these shoes as a foundation in the treatment and correction of foot disabilities. We do not claim that these shoes will correct abnormal foot conditions, but they will provide the types of basic footwear necessary as a foundation in aiding foot trouble and in offering foot comfort. We know you will be glad to recommend them.

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• **Duration** • **Clinical Effectiveness** • **Clinical Tolerance** • **Speed**
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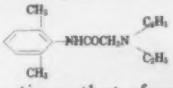
Trade Name : XYLOCAINE **Generic Name** : lidocaine*

Chemical Name: α-Diethylaminoaceto-2,6-xylidide

Chemical Structure:



Potency : Two to three times that of procaine.

Duration of Action : Two to three times that of procaine.

Anesthetic Index : 1.8. **Surface Anesthetic Index** : 8.

Safety Factor : Two to three times that of procaine (because smaller concentrations and volumes are clinically as effective).

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Available on Request : Descriptive literature, bibliography, and trial supply.

Supplied : Vials, 0.5%, 1% and 2% in 20 cc. and 50 cc. without and with epinephrine 1:100,000; 100 cc. vials, 1% without epinephrine. Ampoules, 2 cc., 2% without and with epinephrine 1:100,000.

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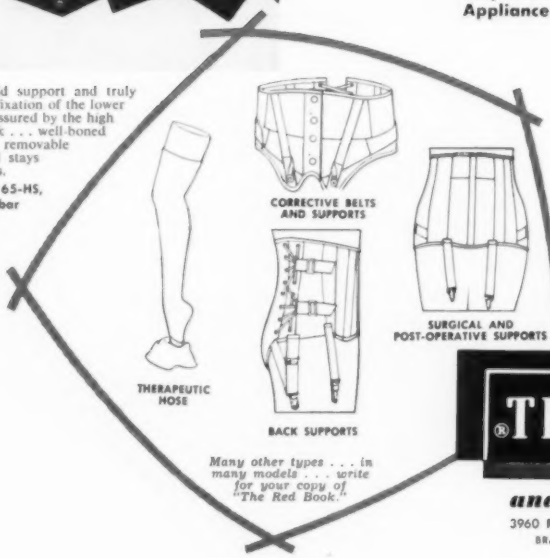
Model 1165-HS, sacro-lumbar support.



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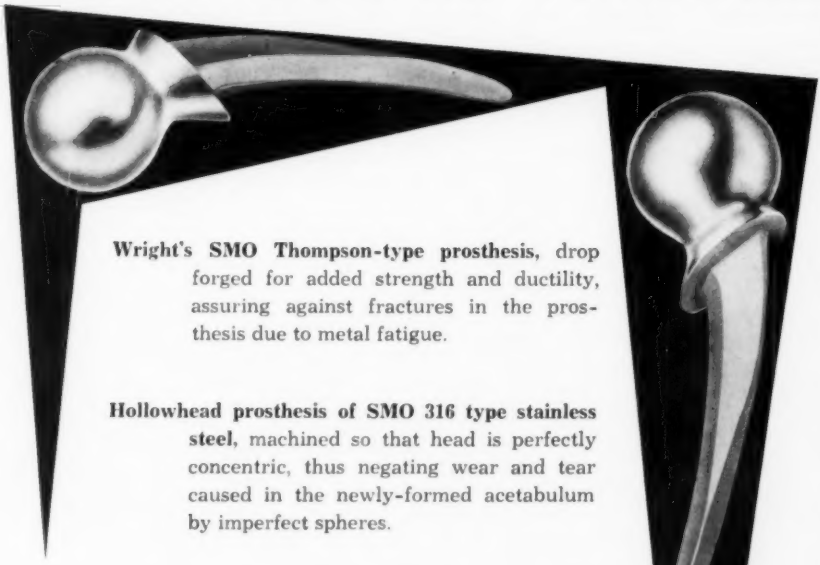
SMo Stainless Steel Drop Forged HOLLOW-HEAD HIP PROSTHESIS



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Hollowhead prosthesis of SMO 316 type stainless steel, machined so that head is perfectly concentric, thus negating wear and tear caused in the newly-formed acetabulum by imperfect spheres.

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HEAD SIZES: 1⅝, 1¾ and 1⅞ inches
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Supplied: Yellow, scored tablets (250 mg.), bottles of [illegible].

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not a mephenesin derivative

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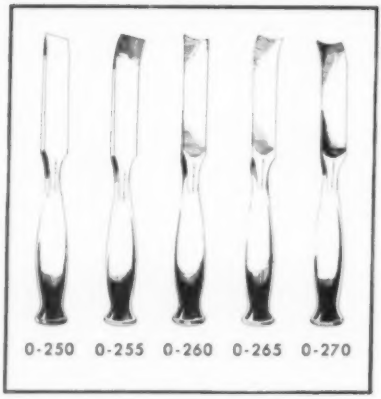

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Specify Width of Gouges and Osteotomes When Ordering

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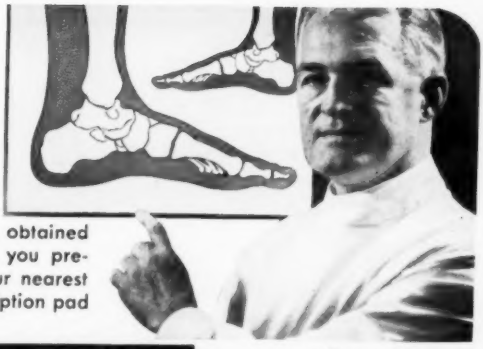

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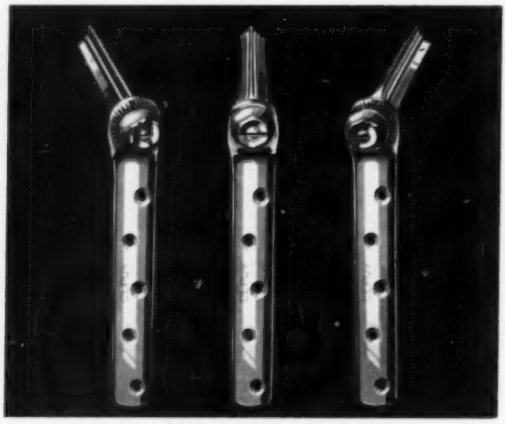
The First Completely Adjustable Intertrochanteric Bone Plate!

The new DePuy Universal Bone Plate is designed to provide *both* vertical and lateral angulation. In use with conventional Smith-Petersen Nails, cannulated or non-cannulated, or with Lorenzo Screws it can be regulated quickly and easily during surgery to suit a wide variety of anatomical conditions. Bending of the plate is *not* required. A range of 35° in the vertical plane of the plate and nail or screw compensates for variance of angle between the femoral head and shaft of the femur. *Also*, there is a 25° range of lateral adjustment which permits the plate to be moved into flush position after the nail or screw has been impacted. Once angulation is properly adjusted rigid fixation is assured by exclusive concave, serrated locking washer, which is held in place with either the double locking screw combination or a solid Hex bolt.

• VERTICAL ANGULATION

The elongated concave surface on the proximal end of the plate combined with an oversize hole permits vertical angulation through 35°. Thus the angular relation of the femoral head to the shaft of the femur can be varied from a minimum of 110° to a maximum of 145° (see photo above). This wide range permits the duplication of practically every anatomical condition. Since bending of the plate is not required no undue stress or strain is set up before the plate is affixed. This fact plus the use of finest SMO stainless steel mean greater strength in the DePuy Universal Bone Plate.



• LATERAL ANGULATION

After the nail or screw has been aligned, driven, and impacted, the plate can be affixed at the correct lateral angle to assure flush placement on the femoral shaft. The underside of the proximal end of the plate has serrated, concave sides to permit rigid fixation in the lateral plane. The concave, serrated locking washer has been formed to correctly match the serrations of the outer convex surface of the head of the plate. This washer, while very strong, can be compressed against the plate for secure bonding when the bolt or double locking screw is tightened.

Write for additional information!

DePuy Universal Bone Plate, No. 693.

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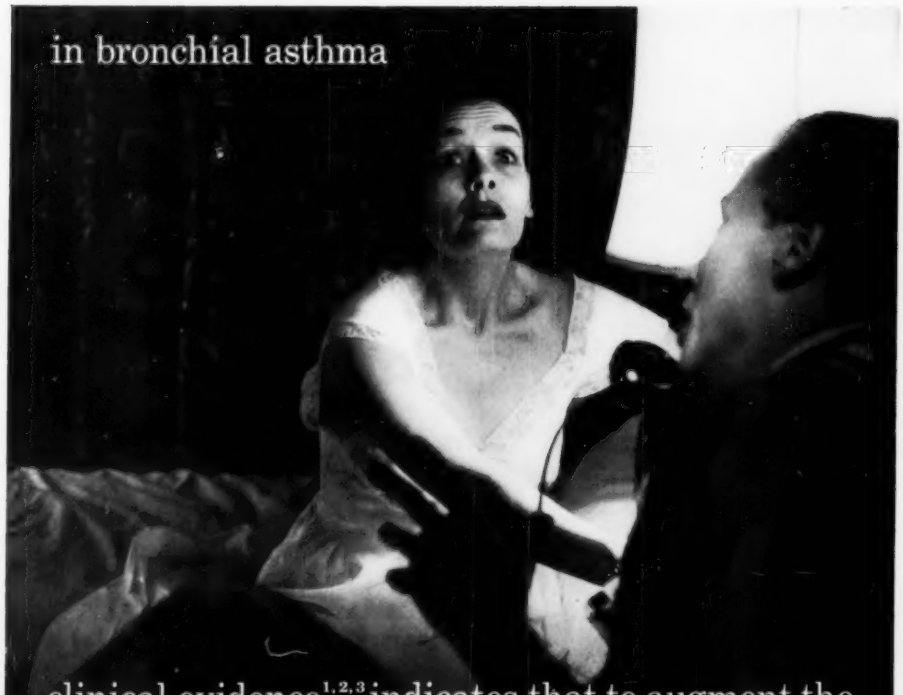
in bronchial asthma
clinical evidence[1,2,3] indicates that to augment the therapeutic advantages of the "predni-steroids" antacids should be routinely co-administered to minimize gastric distress

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(Buffered Prednisone)

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References: 1. Boland, E. W., *J.A.M.A.* **160**:613, (February 25,) 1956. 2. Margolis, H. M. *et al*, *J.A.M.A.* **158**:454, (June 11,) 1955. 3. Hollet, A. J. *et al*, *J.A.M.A.* **158**:459, (June 11,) 1955.

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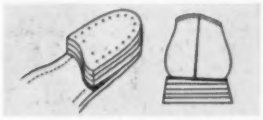

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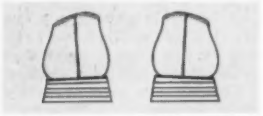
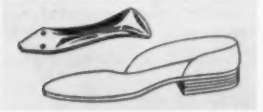


INDIVIDUAL LEFT AND RIGHT QUARTERS CONFORMING TO CHILD'S ANKLE BONES



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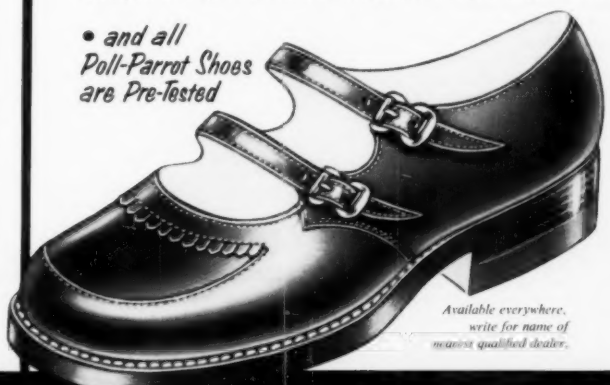
• *and all Poll-Parrot Shoes are Pre-Tested*



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As a result of this continuing effort, HANGER is developing and testing new ideas, new methods, and new materials. From these activities have come many outstanding achievements, adding greatly to the comfort and ever-increasing utility of Prosthetic Appliances. Some of these are shown on this page.

This program is cooperatively carried on by the many HANGER Companies in key cities throughout the United States. The results are available to you through any HANGER office. These efforts continue today, and will in the future—studying, planning, and developing new improvements to produce an ever-better Prosthesis.

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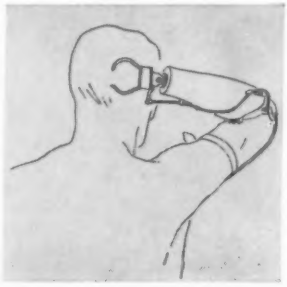

CINEPLASTY

Studies on muscle physiology in the cineplastic muscle motor have been conducted at the Army Prosthetics Research Laboratory and Navy Medical Centers. HANGER has been extremely interested in cineplastic developments, and has furnished a number of Prostheses in connection with this research. As a result, HANGER has developed the "Cinematic" Arm, designed for application to patients with cineplasty operations.

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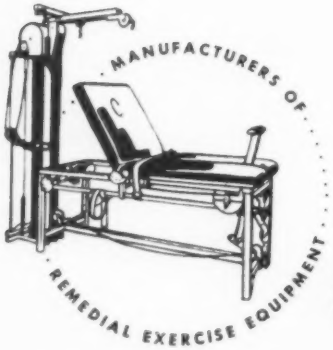

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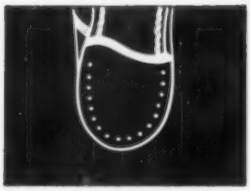

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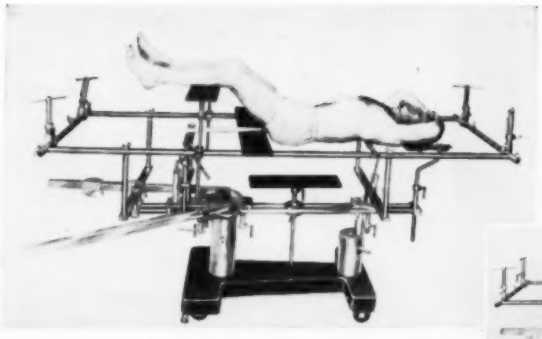

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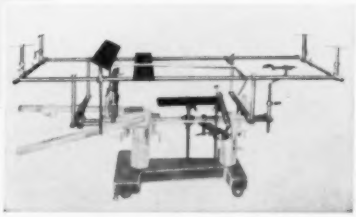

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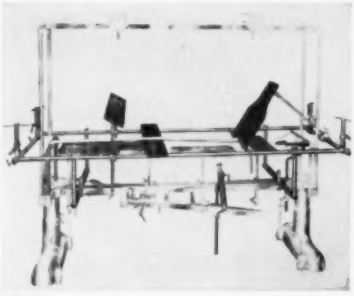
Risser Scoliosis Attachment on Bell Table



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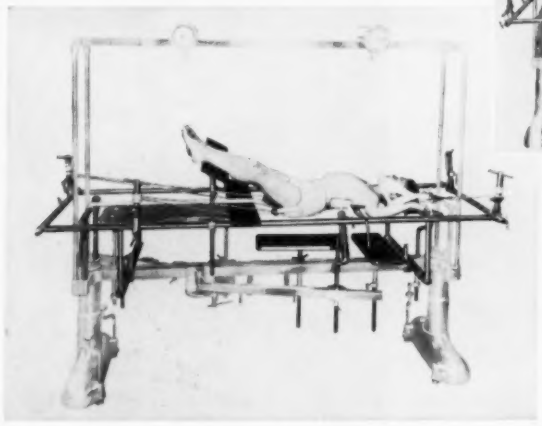

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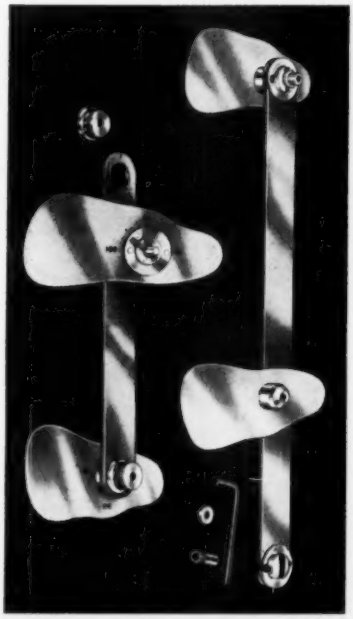

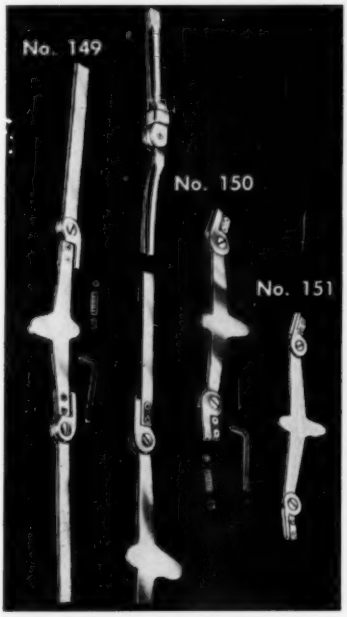

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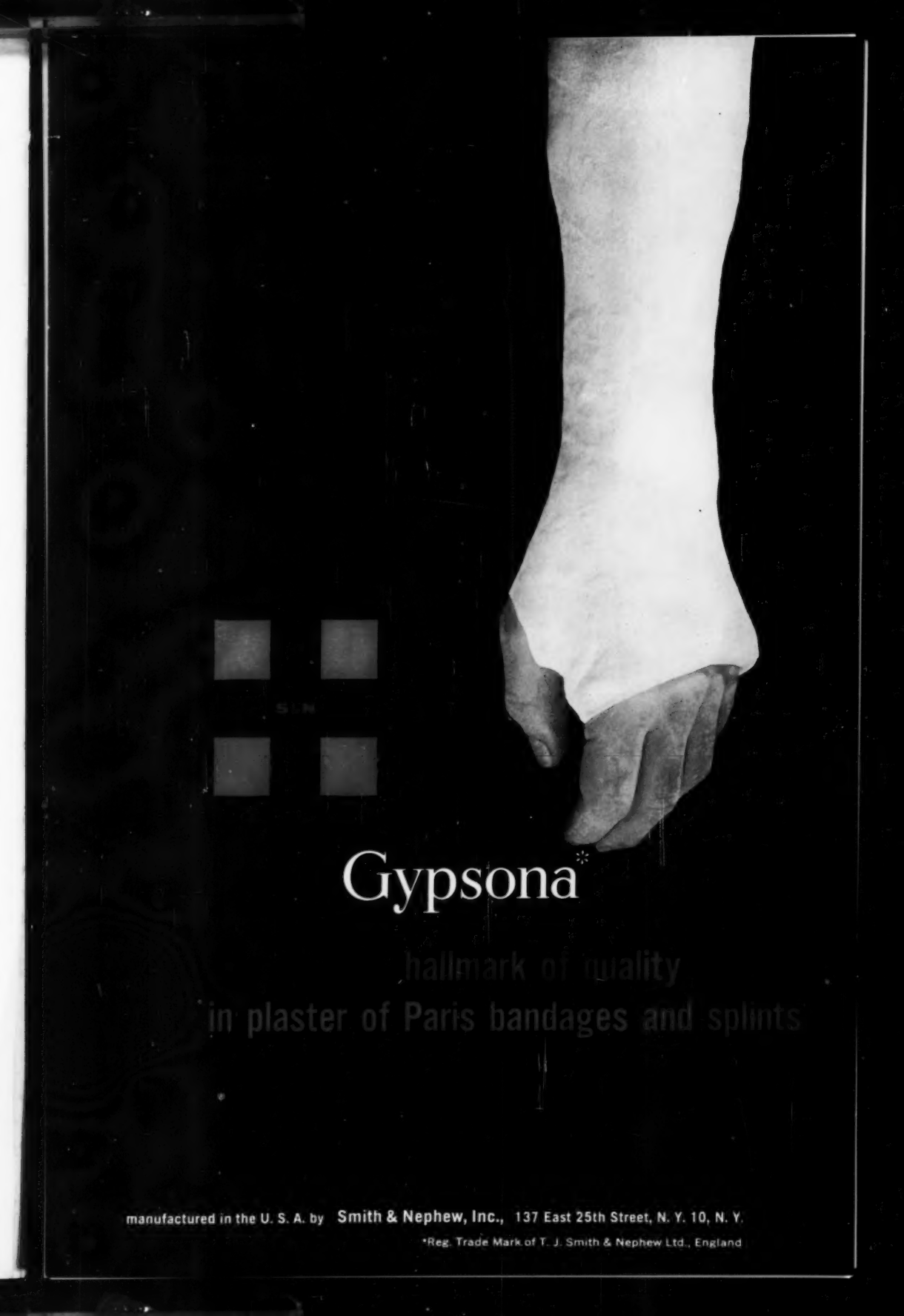
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Prognosis in Dislocations of the Shoulder *

BY CARTER REDD ROWE, M.D., BOSTON, MASSACHUSETTS

From the Shoulder Clinic, the Massachusetts General Hospital, Boston

Contributions to the literature on dislocations of the shoulder have consisted principally in reports of operative techniques for repair of recurrent dislocation and of pathological findings at operation. McLaughlin and Cavallaro, in 1950, reporting 101 consecutive patients, broadened the study of prognosis in shoulder dislocations to include recurrences in relation to age groups, fractures, and subacromial-cuff derangements.

The material for this study consists of admissions over the past twenty years to

TABLE I

SHOULDER DISLOCATIONS (1934–1954)

Admitted to Massachusetts General Hospital	466
Treated by Staff in other hospitals	20
Total number of patients	488
Primary dislocations	398
Recurrent dislocations	102
Total number of shoulders	500
Follow-up for over twenty years	4
Follow-up from ten to twenty years	38
Follow-up from five to ten years	115
Follow-up from one to five years	156
Total follow-up study (shoulders)	313 (63%)
Mean period of follow-up	4.8 years

the Massachusetts General Hospital for shoulder dislocation (Table I). Those patients followed by members of the Staff in other hospitals are also included. We realize that our figures can include only those who come to the hospital for treatment. However, admissions to a large metropolitan hospital are representative of all age groups, various occupations, and many nationalities. A twenty-year period was taken in order to evaluate more accurately the incidence of recurrence, as well as the efficacy of treatment.

During this period, 488 patients (500 shoulders) were treated for shoulder dislocation.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Los Angeles, California, February 2, 1955.

Follow-up studies were completed on 313 shoulders (63 per cent); 398 were initial or primary dislocations and 102 were established recurrent dislocations. The recurrence rate in 398 initial dislocations was 38 per cent. Four patients were followed for over twenty years, thirty-eight from ten to twenty years, 115 from five to ten years, and 156 from one to five years. The follow-up period averaged 4.8 years. The youngest patient recorded with shoulder dislocation was six months of age and the oldest was eighty-nine years of age.

TYPES OF DISLOCATION

Dislocations occurred anteriorly in 98 per cent of the patients, and posteriorly in 2 per cent. In the group with anterior dislocation, both the subcoracoid and subglenoid (inferior) positions were included. The anterior position is not always constant and may vary in position before reduction is accomplished. The subcoracoid position was noted three times more frequently than the subglenoid position.

TABLE II

TYPES OF DISLOCATION

Type	Atraumatic (*No. of Cases*)	Traumatic (*No. of Cases*)
Number of dislocations	22 (4%)	478 (96%)
Number followed-up	14 (64%)	273 (57%)
Incidence of recurrence	12 (86%)	155 (57%)
Characteristics	1. Variation in shape of humeral head, and in size and shape of glenoid fossa. 2. Supporting muscles of shoulder not well developed. 3. High incidence of recurrence.	1. Humeral head defects more common. 2. Usually normal supporting muscles of shoulder. 3. Lower incidence of recurrence. 4. Recurrences occurred easily with little trauma or infrequently with forceful trauma.

Dislocations may also be grouped as *atraumatic* and *traumatic* (Table II). Dislocations as the result of paralysis were not included in this study. Atraumatic dislocations numbered twenty-two (an incidence of 4.4 per cent). These occurred as the result of minor incidents such as raising the arm or moving during sleep. Dislocations in this group were characterized by mild variation in the shape of the humeral head and by variation in the size and the depth of the glenoid fossa. The patients were noted frequently to have hyperflexible joints. Most of them had relatively poor supporting muscles of the shoulder joint. A few had some degree of muscle imbalance. A high incidence of recurrence was noted in patients with atraumatic dislocation. In twelve of the fourteen patients followed dislocation recurred (86 per cent). It was of interest to note that four of eighteen (20 per cent) in this group had moderate humeral-head defects and five of eighteen (30 per cent) had mild humeral-head defects, although no trauma had been associated with the dislocation. Of five shoulders operated on in this group, two had typical Bankart findings at operation and three had no evidence of trauma to the labrum or capsule. Dislocations produced by varying degrees of trauma were characterized by normal supporting muscles of the shoulder. The incidence of recurrence in this group (56 per cent) was lower than that in the patients with atraumatic dislocation. Recurrences occurred either frequently with little added trauma or infrequently with appreciable trauma. At operation, a variety of the effects of trauma were reported, such as tearing of the

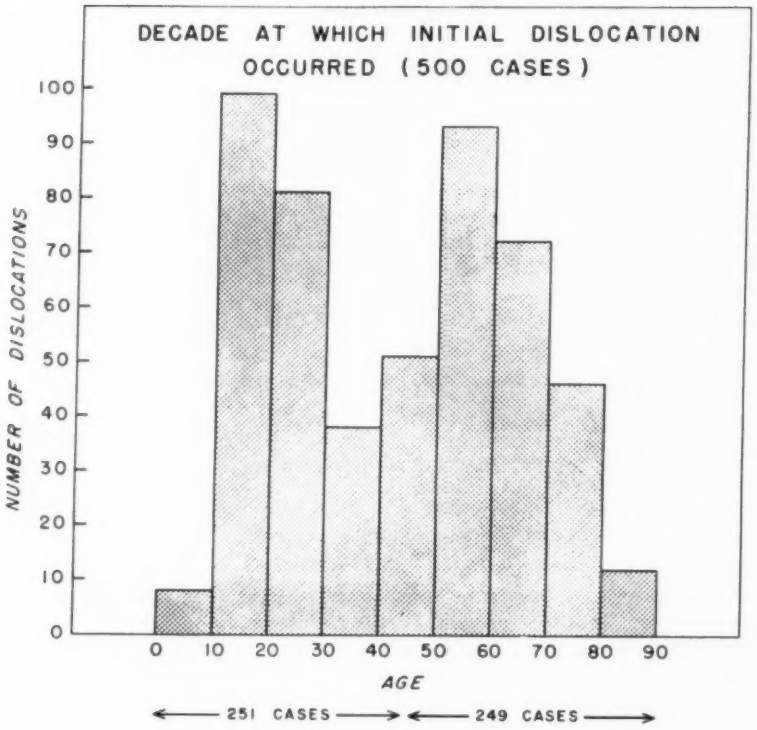

CHART I

capsule from the neck of the humerus or from the neck of the scapula, as pointed out by Nicola, or partial or complete separation of the glenoid labrum and capsule from the anterior glenoid rim, as shown by Bankart, or injury to the musculotendinous cuff, as observed by McLaughlin. Varying degrees of trauma to the subscapularis muscle may occur. The head of the humerus may be unharmed or may be cleaved over the glenoid rim.

AGE OF PATIENT

Our figures indicate that the most consistent and significant factor influencing prognosis in shoulder dislocation is the age of the patient at the time of the initial or primary dislocation. We were able to obtain information in 500 dislocations relative to age of the patient at the time of initial injury. We found that the greatest number of dislocations occurred for the first time between ten and twenty years of age (ninety-nine primary dislocations). The next highest number occurred between fifty and sixty years of age (ninety-three primary dislocations).

Of much interest was the finding that dislocations occurred as frequently after age forty-five (249 dislocations) as before the forty-fifth year (251 dislocations) (Table III and Chart I).

In patients with primary dislocation the mean age was forty-eight years, while in patients with recurrent dislocation the mean age was twenty-three years.

The incidence of *recurrent* shoulder dislocation was determined by the recurrence rate of the group admitted to the hospital with initial dislocations. It was rather surprising to find such a high recurrence rate in patients under twenty years of age (83 per cent) (Table IV). Of equal significance was the small number of recurrences in patients

TABLE III

THE FREQUENCY DISTRIBUTIONS, WITH RESPECT TO AGE, OF DISLOCATIONS DIAGNOSED INITIALLY AS PRIMARY OR AS RECURRENT.

Age Interval	Initial Diagnosis		
	Primary	Recurrent	Total
0–10	6	2	8
10–20	51	48	99
20–30	47	34	81
30–40	30	8	38
40–50	44	7	51
50–60	90	3	93
60–70	72	0	72
70–80	46	0	46
80–90	12	0	12
	398	102	500

after the age of fifty (12 per cent). Our findings compare closely with the figures reported by McLaughlin and Cavallaro in 1950 (Table IV).

One would expect the highest recurrence of dislocation between ages of ten and thirty, during the most active and strenuous periods of life; likewise one would expect a decrease in recurrence after the age of fifty. It is interesting to speculate on the reasons the incidence of primary dislocation after fifty is so high, whereas the recurrence rate at this age falls off so rapidly. Perhaps one becomes much more cautious following a dislocation after the age of fifty. Shoulders in the older group of patients recovered much more slowly because of the stiffness and limitation of motion which persisted in many for months. Another possible reason for the diminishing rate of recurrence after fifty years of age may be the shorter span of life. In the younger group of patients, recovery and return to full activity occurred usually within a relatively short time. Perhaps the younger patients do not allow sufficient time for the maturation of tissue healing and fibrous-tissue formation.

TRAUMA

The degree of trauma associated with the initial dislocation seemed to affect the incidence of recurrence. All phases of trauma in relation to dislocation were considered:

1. Trauma as experienced in the mechanism of injury causing the dislocation;
2. Fractures of the shoulder girdle associated with dislocation;
3. Nerve injuries associated with dislocation;
4. The ease or difficulty of reduction.

TABLE IV

Age	Incidence of Recurrence	
	McLaughlin and Cavallaro's Study (*Per cent*)	This Study (*Per cent*)
Under 20 years of age	90	83
Between 20 and 40 years of age	60	63
Over 40 years of age	10	16

1. *Mechanism of Injury*

Bankart, in 1928, noted that recurrent dislocation, rarely, if ever, occurred in type 1 or "ordinary" dislocations. These were dislocations which resulted from an indirect violence, such as forceful abduction, or levering the head of the humerus out of the joint. However, recurrences were "common" in type 2, or those resulting from direct violence, such as a direct blow to the shoulder or elbow, thus shearing off the capsule from the neck of the glenoid or the labrum from the rim of the glenoid.

Our findings were not consistent with Bankart's generalizations. In the group admitted with initial dislocation in which the dislocation was produced by a twisting injury, or forceful abduction, levering the head of the humerus out of the joint (type 1 of Bankart), the recurrence rate was high (56 per cent). In this group Bankart noted only "rare" redislocation.

In the group in which dislocation was produced by a forceful, direct blow to the anterior or posterior aspect of the shoulder itself, with appreciable impacting force (Bankart type 2), the incidence of recurrence was notably lower (19 per cent). In this group Bankart stated that recurrences were "common".

TABLE V

INCIDENCE OF RECURRENCE IN RELATION TO TYPE OF INJURY
(Initial Dislocations)

Type of Injury to Shoulder	Frequency (*No. of Cases*)	Followed-up (*No. of Cases*)	Recurred	
			No. of Cases	*Per cent*
No trauma	12	6	5	83
Twisting injury	56	41	23	56
Transmitted trauma	80	58	18	31
Direct blow to shoulder	65	53	10	19
Type of Injury not known	185	54	25	46
Total	398	212	81	38

It seems reasonable to assume that if a dislocation occurs easily, it may recur easily and that if little trauma is produced initially, little repair is stimulated. Nicola has shown in his series of open reductions on primary dislocations, that in hyperabduction the capsule tears from the neck of the humerus; but in those cases in which an impacting force is added by a direct or transmitted blow to the shoulder, the capsule is torn from the neck of the scapula, where, if scar formation takes place, or the subscapularis muscle is traumatized, a buttress of repair tissue is created in the area where the head of the humerus commonly dislocates. Our figures lend support to Nicola's findings in that dislocations produced by a direct blow to the shoulder were followed by a lower incidence of recurrence.

The presence of Bankart lesions (an unattached capsule anteriorly, or injury or separation of the glenoid labrum, or erosion and eburnation of the anterior glenoid rim) were noted in a high percentage of patients with recurrent dislocation when the shoulder was examined at the time of operation. We agree with Adams that possibly these lesions do not develop completely at the time of the initial dislocation but develop gradually as the result of repeated dislocations.

In Table V is shown the incidence of recurrence in relation to type of injury causing dislocation. In the group of patients with *no trauma* and the group with *twisting injury*, a high rate of recurrence is registered. The lowest incidence of recurrence is in the group with *direct blow to the shoulder*. This suggests a decrease in recurrence in relation to the

TABLE VI

TYPE OF INJURY IN RELATION TO RECURRENCE AND AGE OF PATIENT

Type of Injury to Patient	Mean Age in Category	Mean Age of Patients with *No* Recurrence	Mean age of Patients with Recurrence
No trauma	20	16	21
Twisting injury	28	49	22
Transmitted trauma	43	57	26
Direct blow to shoulder	47	59	22
Type of injury not known	42	55	24

increased force of the trauma producing the dislocation. In all of the 102 patients admitted with recurrent dislocation an attempt was made to obtain data concerning mechanism of injury. In ten, no trauma was involved; in forty-two, dislocation resulted from twisting injuries; in sixteen, from a direct blow; in eleven, from transmitted trauma. The type of injury was not determined in twenty-two.

The mean age for the respective groups of patients shows consistently higher age averages in the patients in whom dislocation of the shoulder did not recur as compared with those in whom dislocation of the shoulder did recur. The group of patients with *no trauma* is the only exception (Table VI). These figures would suggest, therefore, that the initiating trauma producing the dislocation is significant; however, this must be interpreted also in respect to the age of the patient.

2. *Dislocations Associated with Fractures*

McLaughlin reported no recurrences in thirty-four dislocations associated with fractures of the greater tuberosity. Biebl also found a lower incidence of recurrences with associated fractures. Hill and Sachs found fracture of the greater tuberosity in 37 per cent of the dislocations reviewed by them, but they did not give its relation to recurrence.

In our series of 500 shoulder dislocations, fractures of the shoulder girdle were associated with dislocation in 122 (24 per cent) and with fractures of the greater tuberosity in 15 per cent (Table VII).

The low incidence of recurrence in the group with fracture of the greater tuberosity

TABLE VII

SHOULDER DISLOCATIONS WITH ASSOCIATED FRACTURES
(Incidence of Recurrence)

Site	No.	Total Dislocations (*Per cent*)	Follow-up	Recurred	Incidence of Recurrence (*Per cent*)	
Greater tuberosity	75	15.0	44	3	7	
Fracture-dislocation	10	2.0	4	0	0	
Other fractures:						5.6%
Surgical neck Clavicle Scapula Acromion	10	2.0	5	0	0	
Fracture of anterior glenoid rim	27	5.4	21	13	62	
Total	122	24.0	74	16	22	

TABLE VIII

SITE OF ASSOCIATED FRACTURES IN RELATION TO RECURRENCE AND AGE OF PATIENT

Site	No. of Patients	Average Age	Average Age of Patients with No Recurrence	Average Age of Patients with Recurrence
Greater tuberosity	34	59	61	36
Fracture-dislocation	4	55	55	none recurred
Other fractures	5	51	51	none recurred
Fracture of anterior glenoid rim	20	38	58	25

(Table VII) may be due in some respects to increased trauma; that is, increased hemorrhage and tissue trauma with subsequently greater stimulation to repair and scar-tissue formation. On the other hand, as shown in Table VIII, fractures of the greater tuberosity occur in older patients, the average age being fifty-nine years.

In the patients with dislocation complicated by fractures of the anterior glenoid rim, the recurrence rate indicates a definite mechanical factor predisposing to recurrence.

The severe trauma produced by a fracture-dislocation is significant, as none of the dislocations in patients in this group recurred.

3. *Nerve Injuries Associated with Dislocation*

Does the low incidence of recurrence (seven of twenty-three) in the group of patients who experienced nerve injury indicate increased trauma producing the dislocation, or a longer period of rest for the shoulder after reduction? Were associated fractures a factor?

In twenty-two dislocations associated with nerve injuries, eighteen were produced by severe direct blows to the shoulder or appreciable transmitted force with blows to the elbow or out-stretched hand; three were due to twisting injuries; only one dislocation occurred with no history of trauma—this was complicated by minor nerve injury only. In patients with dislocations thus produced, immobilization of the shoulder after reduction also seemed to have some effect on recurrence. Of nine dislocations with two weeks or more of immobilization, 12 per cent recurred; of eight dislocations with one week or less of immobilization, 50 per cent recurred.

Seven patients (26 per cent) had associated fractures; five of these had fracture of the greater tuberosity which was associated with more severe nerve injury. In these

TABLE IX

EASE OR DIFFICULTY IN REDUCTION

Method	Total Incidence	Follow-up	Recurred	Incidence of Recurrence (*Per cent*)
Self reduction	34	30	28	93
Easy reduction (no anaesthesia but manipulated)	64	52	24	46
More difficult reduction (anaesthesia required)	155	124	50	40
Very difficult reduction (repeated attempts or open reduction)	21	10	0	0

patients only one of the dislocations associated with fracture recurred, this being in a patient with fracture of the greater tuberosity (14 per cent).

4. *Trauma in Relation to Reduction of Dislocation* (*Table IX*)

The difficulty or ease with which reduction is accomplished seemed to be significant. The highest rate of recurrence was in patients in whom reduction was automatic or in patients in whom the dislocation was reduced easily by the patient himself or a friend, shortly after dislocation. The recurrence rate in this group was 93 per cent. In patients with dislocation requiring average manipulation, the easy and difficult groups had a lower rate of recurrence. In patients in whom reduction of the dislocation was most difficult there were no recurrences.

On analysis of these figures in respect to age and associated fractures, we find that these two factors assume significance:

1. *"Self reduction" group:* In 93 per cent of the patients in this group dislocation recurred. The average age was nineteen years (thirty patients). The average age of patients in whom dislocation did not recur was thirty years. The average age of those in whom dislocation did recur was eighteen years. The incidence of associated fractures was 9 per cent which was of no significance in this group of patients.

2. *"Easy reduction" group:* In 46 per cent of the patients in this group dislocation recurred. The average age was thirty-nine years (fifty-two patients). The average age of patients in whom dislocation did not recur was fifty-nine. The average age of those in whom dislocation did recur was twenty-three years. The incidence of associated fractures was 15 per cent, which did not seem to be of statistical significance.

3. *The "more difficult" group:* In 40 per cent of the patients in this group dislocation recurred. The average age was forty-four years (109 patients). The average age of the patients in whom dislocation did not recur was fifty-four years. The average age of those in whom dislocation did recur was twenty-seven. Fractures were associated in this group in 23 per cent of the patients (twenty-nine); of these, dislocation did not recur in 90 per cent.

4. *The "very difficult" group:* In these patients there were no recurrences. The average age was fifty-three years (nine patients). Fractures had occurred in 33 per cent of these patients. Thus trauma, as well as age, seems to bear some relation to the low incidence of recurrence in this group. The foregoing suggest that trauma bears a definite but somewhat variable relationship to the incidence of recurrence. The pattern of recurrence in relation to the age of the patient, however, varies little and seems to be the most consistent determining prognostic factor.

IMMOBILIZATION FOLLOWING INITIAL DISLOCATION

White, in 1928, recommended that no immobilization be used following dislocation, but advocated early motion, massage, and restoration of muscle tone. He reported only two recurrences but did not report these in relation to the total number of patients treated. Davis, in 1936, reported a 25 per cent rate of recurrence in a two-year follow-up study. In his patients the shoulder was strapped to the side in adduction and internal rotation for a period of two weeks. Davis did not tabulate the age of the patient and the other factors for this group.

When this study was begun, we hoped that we could show that an adequate period of immobilization following initial dislocation would perhaps lower the incidence of recurrence—at least in the younger age group. Before we can be certain that immobilization plays a more significant role in the incidence of recurrence after initial dislocation, a larger follow-up series will be necessary.

Information relative to immobilization was obtained in 278 dislocations (Table X).

The highest incidence of recurrence was noted in the groups treated with *no immobilization*, *sling for one week*, and *strapping for one week*. The incidence of recurrence

TABLE X

RECURRENCE OF DISLOCATION IN RELATION TO TYPE AND DURATION OF IMMOBILIZATION, AND TO AGE OF PATIENT

Type of Immobilization	No. of Dislocations	Incidence of Recurrence (*No. of Cases*)		Average Age of Patients in whom Dislocation Did not Recur	Average Age of Patients in whom Dislocation Did Recur
No immobilization	63	52 (83%)		60	21
Sling					
1 week	23	19 (83%)		53	21
2 weeks	23	10 (43%)	61%	57	27
3 weeks	15	8 (53%)		58	28
4 weeks	11	4 (36%)		70	27
5 weeks	5	3 (60%)	48%	55	34
6 weeks	7	4 (57%)		56	16
Total sling	84	48 (57%)			
Sling and swathe					
1 week	18	5 (28%)		60	46
2 weeks	24	13 (54%)	35%	51	31
3 weeks	26	6 (23%)		55	20
4 weeks	14	8 (57%)		57	16
5 weeks	4	2 (50%)	54%	64	18
6 weeks	10	5 (50%)		52	17
Total sling and swathe	96	39 (41%)			
Strapping to body					
1 week	5	5 (100%)			32
2 weeks	5	3 (60%)	60%	67	20
3 weeks	5	1 (20%)		39	20
4 weeks	6	4 (67%)		52	17
5 weeks	4	2 (50%)	60%	36	19
6 weeks	5	3 (60%)		41	22
Total strapping to body	30	18 (60%)			
Cast					
4 weeks	2	2 (100%)			14
Total All Types	275	159 (58%)			

for patients treated one week in *sling and swathe* was, for some reason, unusually low (28 per cent).

The remaining groups showed an over-all lower incidence of recurrence, but these recurrences seemed equally distributed and not associated with type of support or length of immobilization of the initial dislocation.

It was interesting to note that there was no lowering of the incidence of recurrence in patients with shoulders immobilized for three weeks as compared with those whose shoulders were immobilized for six weeks.

The lowest incidence of recurrence was found in patients treated by four weeks in a sling, by three weeks in sling and swathe, and by three weeks of strapping. Perhaps three weeks of immobilization may be sufficient time for healing to occur. After this time exercises may be started.

The most significant factor again was age, as shown by the consistent finding of an older age average in those patients in whom dislocation of the shoulder did not recur as compared with the younger age average for those in whom dislocation did recur.

The occurrence of associated fractures was reviewed in relation to this grouping and was found to be of questionable significance.

Seven of the sixty-three patients treated with no immobilization had experienced fractures. All of them were of the anterior glenoid rim, which predisposes to recurrence, but the number is small and not significant.

Of the ninety-six patients treated by sling and swathe, twenty-nine had fractures, twenty-two of which were fractures of the greater tuberosity. In the eighteen thus treated for one week two had fractures of the greater tuberosity (recurrence rate for group, 28 per cent); in the twenty-four patients treated thus for two weeks, there were seven fractures of the greater tuberosity (recurrence rate for group, 58 per cent); and in the twenty-six patients treated thus for three weeks, there were six fractures of the greater tuberosity (recurrence rate for group, 22 per cent). These data do not indicate a consistent response to the complication of fracture of the greater tuberosity. In the thirty treated by strapping there were seven fractures, two of them of the greater tuberosity. These were not significant.

FIG. 1

Roentgenogram showing a severe "hatchet" defect in a boy seventeen years old. Dislocation was caused by an epileptic attack. Bankart repair was done in 1946; there has been no recurrence since that time.

The type of injury producing the dislocation was reviewed in these groups and was found to be of little significance. It is suggestive, therefore, that a high recurrence rate is associated with no immobilization and with short periods of immobilization. Moderate periods of immobilization were associated with lowering of the recurrence rate. The rate of recurrence was not further lowered by long periods of immobilization.

HUMERAL-HEAD DEFECTS

A defect in the posterior lateral surface of the humeral head associated with dislocation of the shoulder has definite significance in prognosis. More attention has been paid to this finding since the report of Hill and Sachs, in 1940, and since the Symposium on Recurrent Dislocation of the Shoulder in the British Volume of *The Journal of Bone and Joint Surgery* in 1948.

Hill and Sachs found the defect present in 27 per cent of 119 initial shoulder dislocations, and in 74 per cent of fifteen recurrent shoulder dislocations. Eyre-Brook reported an incidence of 64 per cent in seventeen recurrent dislocations of the shoulder, and Brav an incidence of 67 per cent in sixty-nine recurrent dislocations of the shoulder. Adams reported 82 per cent in sixty-eight shoulder dislocations operated upon. Palmar and Widen reported 100 per cent in sixty cases operated upon, as did Bost in ten cases operated upon. The need for careful roentgenographic technique in order to demonstrate the defect is stressed by these authors.

FIG. 2-A

FIG. 2-B

Fig. 2-A: Roentgenogram illustrates the relationship between the defect and the anterior glenoid rim in a man seventy-four years old. Injury was caused by a fall in 1950.

Fig. 2-B: Roentgenogram made after reduction. There had been no recurrence five years after reduction.

In our series, we were able to report on 125 patients with primary dislocations, in 38 per cent of whom there were humeral-head defects, and on sixty-three patients with recurrent dislocation, in 57 per cent of whom there were humeral-head defects. In these patients satisfactory roentgenographic studies were done; that is, anteroposterior views in neutral position, in 50 to 70 degrees of internal rotation, and, in many instances, axial or axillary views. We have classified the defects in our series as mild defects (20 per cent), moderate defects (30 per cent), and severe or deep defects (50 per cent). The defect is usually in the posterolateral surface of the head, and in a great majority of cases is noted on the anteroposterior view in 50 to 60 degrees of internal rotation. Axillary views are a definite help, and should be made for all patients if possible. However, we had several instances in which the defect was visualized on the anteroposterior roentgenogram with the arm in internal rotation; it was not seen in the axillary view. The vertical line of sclerosis may be very helpful in localizing the defect.

In order to determine the incidence of humeral-head defects in shoulders which have never dislocated, the roentgenograms of 200 patients seen in the Shoulder Clinic who gave no history of dislocation but complained of shoulder, neck, or arm pain were examined. No shoulder was included which had not had satisfactory, multiple roentgenograms made. It was interesting to find that mild defects were present in 4 per cent, moderate defects were present in 5 per cent, and severe defects in 1.5 per cent. The severe defects were in patients who had had some injury of the shoulder but who had not experienced dislocation. These findings suggest that defects of the humeral head are produced by trauma to the shoulder rather than by actual dislocation.

Brav reviewed 100 shoulders with no history of dislocation and noted no well defined humeral-head defects or vertical lines of sclerosis. There was, however, in twenty-eight shoulders flattening of the humeral head, which may correspond with our classification *mild defects*. Whether these are actual defects is difficult to say. They are most likely attritional changes in the humeral head at the insertion of the musculotendinous cuff. Examples of typical humeral-head defects are shown in Figures 1, 2-A, and 2-B.

Trauma seemed to be the origin of the humeral-head defects. There was one instance

TABLE XI

HUMERAL HEAD DEFECTS

(Incidence from X-Ray Examinations)

	X-rays Examined	Head Defects (*Superior Lateral*)	(*Per cent*)
Shoulders with no history of dislocation	200	21	10
Primary dislocations	125	47	38
Recurrent dislocations	63	36	57
Operations for recurrent dislocation	54	32	59
Epileptics	8	8	100

in our series in which a complete roentgenographic survey had been done on a patient prior to dislocation. The roentgenograms were normal. After a traumatic dislocation of his shoulder, roentgenograms were again made; these showed a definite, severe humeral-head defect. Hill and Sachs also report an instance such as this. In those instances in our series in which it was necessary to reduce the head surgically from the rim of the glenoid, the appearance of the humeral-head defect indicated trauma. The high incidence (100 per cent) of humeral-head defects in epileptics also indicates traumatic origin. Of thirty-nine patients with humeral-head defects in our series, 84 per cent had definite history of trauma.

1. *Incidence of humeral-head defects in relation to other pathological conditions in the shoulder:* Of the eighty-two shoulders operated on satisfactory roentgenograms were available in only fifty-four. Of these 59 per cent demonstrated humeral-head defects (Table XI). Bankart lesions were present in 90 per cent of shoulders operated on. The most frequently noted single Bankart lesion was some significant damage to the glenoid labrum (85 per cent). No Bankart findings were noted in 10 per cent; of these 50 per cent had humeral-head defects.

2. *Humeral-head defects in relation to prognosis:* The presence of a humeral-head defect would seem to indicate increased shoulder instability and a greater chance of recurrent dislocation. For instance, the incidence of head defects in the group of patients with no history of dislocation was 10 per cent; in the group of patients with primary dislocation it was 38 per cent; in the group of patients with recurrent dislocation it was 57 per cent; and in the patients subjected to surgery for recurrent dislocation it was 59 per cent. In the 125 primary dislocations, the seventy-eight shoulders which had no humeral-head defects as seen by roentgenogram, there was an incidence of recurrence of 50 per cent, whereas in the forty-seven shoulders with humeral-head defects dislocation

TABLE XII

HUMERAL HEAD DEFECTS IN RELATION TO SURGERY FOR RECURRENT DISLOCATION

Operation	With Adequate X-Rays	Follow-up Incidence of Head Defects (*Mild*)	(*Moderately Severe*)	(*Severe*)	Incidence of Recurrence
Bankart	43	2	8	13	One
Nicola	6	0	0	2	All
Putti-Platt	4	1	0	2	None
Dickson	1	0	1	0	None
Total	54	3	9	17	

recurred in 82 per cent. Regardless of this rather significant trend, however, the average age of the patients in whom dislocation of the shoulder did not recur but who had humeral-head defects was fifty-eight years and of those in whom dislocation of the shoulder did recur was twenty-three years. What is the prognosis in shoulders with humeral-head defects after surgical repair for dislocation of the shoulder? We had satisfactory information on fifty-four shoulders (Table XII) which had humeral-head defects, and had been subjected to operative repair for recurrence. In three (6 per cent) dislocation recurred;

TABLE XIII

SIDE OF BODY

	No. of Dislocations	Follow-up	No. of Recurrences	Percentage Recurred
Right	238	146	85	58
Left	238	150	84	56

TABLE XIV

INCIDENCE OF RECURRENCE IN 117 PRIMARY DISLOCATIONS IN RELATION TO HANDEDNESS (100 PER CENT FOLLOW-UP)

Right-Handed Patients		*Left-Handed Patients*	
105		12	
Dislocated on right side	Dislocated on left side	Dislocated on right side	Dislocated on left side
48	57	8	4
Recurred	*Recurred*	*Recurred*	*Recurred*
30	35	8	1
(62%)	(61%)	(100%)	(25%)

two of these had been repaired by means of the Nicola operation and one by the Bankart procedure. Of the twenty-three Bankart repairs, there were no deviations from the usual technique in seventeen. From four Putti-Platt procedures and one Dickson procedure there were no recurrences. Patients with shoulders repaired by means of the Bankart technique have been followed for the longest period of time—50 per cent of them have been followed for over five years.

HANDEDNESS

Are the dominant and recessive sides factors in dislocation of the shoulder? Is the recessive, or weaker, side more apt to dislocate because of the relatively weaker supporting structures or poorer muscle coordination than the dominant side? In this series, the weaker or recessive side showed a very small and insignificant increase in the incidence of dislocation. Of 476 dislocations of the shoulder 238 occurred on the right and 238 on the left, with an essentially equal incidence of recurrence (Table XIII). Brav reported forty-one operations for shoulder dislocation, 40 per cent of them were on the right and 60 per cent on the left. In our series of 136 operations for shoulder dislocation, sixty-nine (51 per cent) were on the right and sixty-seven (49 per cent) were on the left. Of 117 patients about whom we had information relative to handedness, 105 were right-handed and twelve left-handed, an incidence of 11 per cent left-handedness (Table XIV). This is somewhat below the normal average incidence of left-handedness which Wile reports as 20 to 25 per cent.

TABLE XV

PATHOLOGICAL CONDITION PRESENT AT OPERATION IN EIGHTY-TWO SHOULDERS

		No. of Cases
Labrum involved		70 (85%)
Labrum absent	26	
Detached from rim	25	
One end free in joint	7	
Bucket-handle split	4	
Frayed but intact	8	
Glenoid rim		41 (50%)
Fractured	10	
Eroded, smooth	31	
Capsule		34 (42%)
Detached or separated from glenoid rim	25	
"Ruptured"	5	
"Redundant"	4	
Loose bodies		9 (11%)
No Bankart findings		8 (10%)
Of these—4 had humeral-head defects		
4 had no head defects		
Pectoralis minus (abnormalities)		2
Absent	1	
Attached to head of humerus	1	

In the 105 right-handed patients in our series, forty-eight initial dislocations were on the right (62 per cent of which recurred) and fifty-seven initial dislocations were on the left (61 per cent of which recurred). Thus, there are only nine more dislocations (8 per cent) on the weaker side; yet there is no increase in the incidence of recurrence. *Of the twelve left-handed patients*, four dislocations were on the left (one recurred) and eight were on the right (all recurred). Of seven patients with bilateral dislocation, five were right-handed, one was left-handed, and one was ambidextrous.

There is, therefore, little convincing evidence that dislocation occurs more often on the weaker or recessive side.

PATHOLOGICAL FINDINGS

It is generally conceded that no single pathological finding accounts for dislocation of the shoulder, but rather that dislocation is the result of individual predispositions, a combination of traumatic factors, and the resultant forces expended at the weakest point of the shoulder. The forces preventing dislocation are a combination of muscle tone and tension from the enveloping rotator musculotendinous cuff group (the subscapularis, supraspinatus, infraspinatus, and teres minor) and the stabilizing force of the deltoid, triceps, and biceps muscle groups. The movability of the scapula and the constant adjusting of the glenoid fossa to different positions of the humeral head give some stability to a very unstable joint. Another factor preventing dislocation of the shoulder is the attachment of the capsule and the glenoid labrum at the rim of the glenoid. This is effective only when there is tension on the capsule as the result of rotation or elevation of the shoulder. When the capsule is torn from its attachment, or the cupping of the glenoid labrum is lost because of detachment or wearing away, a retaining force to the humeral head is lost. A defect in the superior lateral surface of the humeral head may give additional instability to the shoulder in a position of elevation and rotation.

At operation, we found the great majority of shoulder dislocations to be intracapsular dislocations. Very rarely was the capsule perforated by the head (6 per cent in patients operated upon in this series).

TABLE XVI

NERVE INJURY (ASSOCIATED WITH INITIAL DISLOCATION)

Nerve	Total Incidence	Follow-up	Recurred
Ulnar	8 (30%)	7	3
Radial	5 (18%)	4	2
Axillary	3 (11%)	2	1
Medial	1 (4%)	1	
Combinations	10 (37%)	9	1
Total	27 (100%)	23	7

Number temporary paralyses—23; number permanent paralyses—4.

In two cadavera with severe, traumatic, unreduced shoulder dislocations, there was revealed on dissection of the shoulder complete perforation of the capsule and subscapularis muscle, as well as partial avulsion of the rotator cuff. In eleven primary open reductions, the rotator cuff was avulsed in four instances, one of which was complete avulsion of the rotator cuff from the humeral head. The subscapularis muscle was partly perforated in one patient. We may assume that rotator-cuff injury occurs much more frequently than is generally recognized. McLaughlin has emphasized this point.

Of the patients operated upon in this series, 5 per cent showed no evidence of intra-articular derangement or trauma to account for the dislocation. The incidence of pathological findings seen at operation is listed in Table XV.

POSTERIOR DISLOCATIONS

In our series of 500 shoulder dislocations, there were ten posterior dislocations, an incidence of 2 per cent. Biebl reported an incidence of 0.9 per cent in 1935. Wilson cited 1.5 per cent in 260 shoulders in 1949, and McLaughlin reported an incidence of 3.8 per cent in 581 shoulders in 1952.

All of the posterior dislocations in our series were in male patients. The average age was twenty-four years. A definite injury was associated with the initial dislocation in all except one patient in whom a minor degree of muscle weakness had been present since birth. Six of the ten posterior dislocations recurred after initial dislocation. Operations were performed on eight. A definite humeral-head defect was present in three patients. Two of the humeral heads were cleaved over the posterior glenoid rim, necessitating open reduction to displace the head. As was pointed out by Wilson and McLaughlin, the diagnosis of posterior dislocation may be easily missed. One such was undiagnosed for three months; the patient received physical therapy and exercises to no avail. A posterior Bankart procedure was performed on four patients who had recurrent posterior dislocations, and a Nicola procedure was carried out in two patients. In both of the patients who had Nicola procedures dislocation recurred. Three of the four patients in whom posterior Bankart procedures were done have been followed from three to ten years, and the dislocation did not recur. The fourth was lost to follow-up.

The pathological findings in the posterior Bankart operations showed complete separation of the glenoid labrum in one patient and a frayed labrum in another. The capsule was detached posteriorly in two patients.

BILATERAL DISLOCATIONS

Bilateral dislocations were present in twelve patients, an incidence of 2.4 per cent. Of the twenty-four shoulders, we have follow-up information on twenty-two; eighteen of

TABLE XVII

OPERATIONS FOR SHOULDER DISLOCATIONS: INCIDENCE OF RECURRENCE

Method	Number	Follow-up	Recurred	Incidence of Recurrence (*Per cent*)
Bankart	92	75	1	1.3
Bankart-Dickson	2	1	0	0
Bankart-Nicola	3	3	0	0
Nicola	37	32	17	53
Open reduction for initial dislocation	11	11	0	0

the twenty-two dislocations recurred (82 per cent). Bilateral dislocation recurred in eight. The average age was twenty years. Information relative to handedness was obtained in seven patients (fourteen shoulders). One patient was ambidextrous. Five were right-handed and one left-handed. This is within the normal ratio of right to left handedness. Eleven patients were male and one was female. There was one instance of twins with bilateral dislocation of the shoulder. Simultaneous dislocation of both shoulders occurred in only one patient. No history of injury was obtained in three. Nineteen bilateral dislocations were traumatic in origin. Two patients with traumatic bilateral dislocation were epileptic.

EPILEPTICS

Ten patients had epilepsy, an incidence of 2 per cent. Bilateral dislocation occurred in two patients. Roentgenograms were satisfactory in six patients (eight shoulders). Of the eight shoulders, all had severe humeral-head defects. Follow-up information was available for nine patients with epilepsy (eleven shoulders); ten dislocations recurred. Thus, there is a high incidence of recurrence in epilepties and high incidence of humeral-head defects. The average age was twenty-two years. Posterior dislocation of the head was present in one patient; the dislocation was anterior in the remaining nine. All epileptic patients were male.

MALE AND FEMALE

Dislocations were approximately twice as common in the male as in the female (323 males and 165 females). The incidence of recurrence was approximately twice

TABLE XVIII

EVALUATION OF FUNCTION RESULTING FROM FIFTY-NINE BANKART PROCEDURES

Poor	Fair	Good	Excellent
Marked limitation in all motions.	50 per cent limitation in external rotation. 30 per cent limitation of elevation.	25 per cent limitation in shoulder motion.	Essentially normal motion.
Limited in many activities and all sports.	Limited in certain overhead work and sports.	Moderate limitation in sport. Useful shoulder for work.	Very slight limitation in sports. No limitation in work.
Patients not satisfied.	Patients satisfied.	Patients satisfied.	Patients very satisfied.
5 per cent	13 per cent	23 per cent	59 per cent

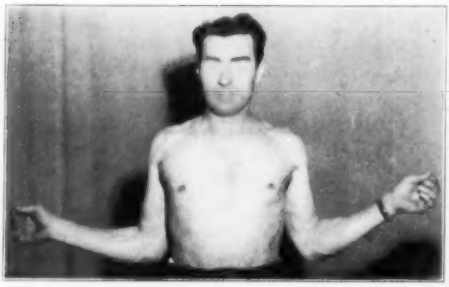

FIG. 3-A

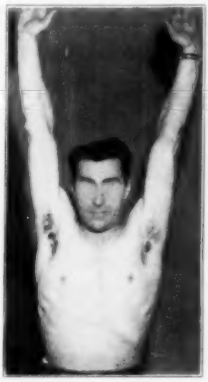

FIG. 3-B

FIG. 3-C

Photographs show an excellent result after Bankart repair. In 1946, the patient, thirty-one years old, fell on the ice. He suffered many recurrences of dislocation of the right shoulder. Bankart repair was done in 1948. Since that time there have been no recurrences. Shoulder motion was normal and there was no limitation of motion at work or at play.

FIG. 4-A

FIG. 4-B

FIG. 4-C

In 1952, the patient injured his right shoulder. Recurrence of the dislocation followed. Bankart repair was done in 1954. Patient has full use of his shoulder. The result was graded *excellent*.

as frequent in males as in females (66 per cent of males and 30 per cent females).

NERVE INJURY IN RELATION TO DISLOCATION

White reported a 20 to 30 per cent incidence of nerve complications, the medial cord being the most frequently involved.

Injury to nerves of the brachial plexus occurred in twenty-seven instances (5.4 per cent), twenty-three nerve injuries were temporary, whereas four were permanent. Nerves arising from the median cord were the most frequently involved. Signs of ulnar-nerve injury were present in eight, radial-nerve injury in five, axillary-nerve injury in three, and median-nerve injury in one. All of the single nerve injuries were temporary. Combinations of nerve injuries accounted for the remaining ten which included also the permanent injuries (Table XVI).

EVALUATION OF SURGICAL REPAIR

The Bankart procedure, or some modification, was used by the majority of our Staff.

Ninety-two Bankart repairs were performed with follow-up in seventy-five. To date there has been but one recurrence of dislocation in seventy-five Bankart procedures (1.3 per cent) (Table XVII). Of the patients subjected to Bankart repair, 55 per cent were followed from one to five years; 45 per cent of them were followed from five to

fifteen years. An evaluation of function is given in Table XVIII. The Bankart operation is a difficult one and it is important that the surgeon have adequate assistance for this procedure. However, the difficulty of the Bankart procedure is somewhat overemphasized; the technical steps are eased to a large extent with proper instruments and positioning of the patient. The operation has proved extremely satisfactory in the hands of our Staff. No effort has been made to restrict external rotation; in fact, an effort has been made to retain as much external rotation as possible. A number of patients have a residual "tight" shoulder, but this was not produced intentionally.

There were many variations in the routine Bankart procedure as used by different members of our Staff. However, the usual anterior exposure was made, the anterior deltoid was turned back, the coracoid was osteotomized, the subscapularis muscle was separated from the anterior capsule, and the capsule was opened anteriorly. It is significant that variations in technique, such as the number of holes in the anterior glenoid rim, the type of joint opening and closure, whether fascia was used to reinforce the anterior capsule, had no effect on the incidence of recurrence. Watson-Jones has mentioned this in respect to the Bankart procedure. However, variations in technique had a definite effect on the resulting range of motion and ease of shoulder function.

Thirty-seven Nicola procedures were performed, with follow-up in thirty-two. Many of the Nicola procedures were performed some years ago and, therefore, lacked recent improvements in technique. In thirty-two patients subjected to the Nicola procedure, dislocation has recurred in the past twenty years in 53 per cent. Adams, in 1948, reported 36 per cent recurrence in fifty-nine military personnel. Lange, in 1951, reported 33 per cent recurrence in a two-year follow-up study. Our findings at operation for recurrent dislocation following the Nicola repair suggest that there would be an increase in the rate of recurrence from the incidence of fraying and wearing away of the transplanted biceps tendon.

Other surgical procedures which have been used are as follows: Putti-Platt (nine operations, two recurrences); Gallie-LeMesurier (four operations, no recurrences); Henderson sling (four operations, four recurrences); the Dickson procedure (two operations, no recurrences), Magnuson-Stack (two operations, one recurrence), and Clairmont-Ehrlich (two operations, two recurrences).

FOLLOW-UP STUDY ON SHOULDERS WITHOUT RECURRENCE AND WITHOUT SURGERY

What then is the prognosis in relation to usefulness of shoulder function in those patients in whom dislocation did not recur and in whom

FIG. 5-A

FIG. 5-B

After recurrence of dislocation of the right shoulder, Bankart repair was done in 1952. Since that time dislocation has not recurred. Patient has limitation of 25 degrees of shoulder motion. Result was graded *good*.

TABLE XIX

TIME INTERVAL OF RECURRENCES FOLLOWING *Initial Dislocation* AND FOLLOWING *Surgical Repair*

Recurrences Following	0–2 Years	2–5 Years	5–10 Years	10–20 Years
Initial dislocation	79 (70%)	21	7	5
			(30%)	
Surgical repair	15 (52%)	5	8	1
			(48%)	
Total	94 (67%)	26	15	6
			(33%)	

surgery was not done? Sufficient information was available on 110 shoulders; sixty-nine (62 per cent) were found to be normal shoulders as regards function and comfort. Twenty-four (22 per cent) demonstrated mild limitation of activities (*good*). Fourteen (13 per cent) had moderate limitation of activities (*fair*); and three (3 per cent) had marked limitation of activities and usefulness (*poor*). Moderate limitation consisted in not trusting the shoulder in elevation and inability at work or to participate in sports requiring the use of the arm in an overhead position. In the group of patients with marked limitation, there was little practical use of the shoulder and a great deal of protection and loss of motion and strength. This group of fair and poor results (16 per cent) may well represent residual rotator-cuff injuries. These figures parallel closely the functional results from the use of the Bankart procedure.

TIME INTERVAL OF RECURRENCES FOLLOWING INITIAL DISLOCATION AND FOLLOWING SURGICAL PROCEDURES FOR RECURRENT DISLOCATION

We have obtained information which may be significant from noting the time interval of recurrences following initial dislocation and following surgical procedures.

Recurrences following initial dislocation: Our figures show that 70.5 per cent of the dislocations recurred within the first two years, 18.7 per cent recurred from two to five years, 6 per cent recurred from five to ten years, and 4.5 per cent recurred from ten to twenty years. Thus 70 per cent of all recurrences may be expected to recur within two years.

Recurrences following operative procedures: 52 per cent of dislocations recurred in the first two years, 17 per cent recurred from two to five years, 28 per cent recurred from five to ten years, and 3 per cent recurred from ten to twenty years. Thus, 52 per cent of recurrences may be expected to recur within two years.

DISCUSSION

Primary shoulder dislocation in general has been considered an injury of youth because of the frequent reports on operative repair or studies based on personnel of military or school age. Our figures gave an equal division of primary shoulder dislocations before and after age forty-five.

The incidence of recurrence, however, was found to be very high in the second decade of life, but showed a marked decrease after age fifty. There is some thought today that an operative repair should be performed in these young patients at the time of initial or primary dislocation because of the very high incidence of recurrence. As 30 per cent of recurrences following primary dislocation occur more than two years after the initial injury, a large group are eliminated from the urgency of surgery. A large

number of these will be symptom-free and will have very good shoulders until there is a recurrence. Therefore, there seems little indication for operative repair on primary shoulder dislocation in patients in the younger age groups.

Other factors relating to prognosis were reviewed, such as trauma, associated fracture, and the type and duration of immobilization. These indicated some significance in relation to recurrence, but when analyzed relative to age groups, the age of the patient was found to be the most important factor influencing prognosis.

The long-term follow-up study of seventy-five Bankart procedures for recurrent dislocation indicates that the procedure is very dependable. A larger group of cases are needed before its long-term effectiveness can be more definitely stated. Our experience with the Bankart operation, however, has demonstrated that it is not necessary to limit external rotation intentionally in order to prevent recurrent dislocation. Rather it has prompted us to plan our operative technique carefully so as to gain maximum rotation and elevation, as these shoulders have proved to be stable with a very low incidence of recurrence of dislocation.

SUMMARY

1. Five hundred shoulders in a series of 488 patients, with a follow-up study on 313 shoulders (63 per cent), are reviewed relative to prognosis.

2. The study included patients treated over the past twenty years, with a mean follow-up period of 4.8 years.

3. In 38 per cent of the patients the dislocation recurred.

4. Primary shoulder dislocations were found to occur as frequently after forty-five years of age as before forty-five.

5. The incidence of recurrent dislocation of the shoulder was very high in the second decade (92 per cent), but showed marked decrease after age fifty (12 per cent).

6. The age of the patient at the time of the primary shoulder dislocation was the most significant single prognostic factor.

7. Throughout this study, the average age of those patients in whom redislocation did not occur was greater than in those in whom dislocation did recur.

8. Various phases of trauma in relation to dislocations were reviewed. Usually the greater the initial injury, the lower was the incidence of recurrence.

9. Fracture of the shoulder girdle was a complication in 24 per cent. The incidence of fracture of the greater tuberosity was 15 per cent. This complication was accompanied by an appreciable lowering of the incidence of recurrence (7 per cent). The exception was in chip fractures of the anterior glenoid rim.

10. Humeral-head defects were present in 38 per cent of the primary dislocations and in 57 per cent of recurrent dislocations. These were associated with an increase in the incidence of recurrence (82 per cent).

11. From our figures, the incidence of recurrence seemed to be affected very little by the type and length of immobilization of the shoulder following dislocation. Although a high incidence of recurrence was noted in the group of patients for whom there was no immobilization or for whom there were very short periods of immobilization, long periods of immobilization were not associated with a significant decrease in recurrence.

12. The incidence of recurrent dislocation relative to handedness was not significant.

13. Following primary or initial dislocation, 70 per cent of the dislocations which recurred did so within two years.

14. Following operative procedures for the repair of recurrent shoulder dislocation, 52 per cent recurred within two years after operation.

15. The incidence of posterior dislocation was 2 per cent.

16. The incidence of bilateral dislocation was 2.4 per cent.

17. The incidence of associated nerve injury was 5.4 per cent.

18. The incidence of epileptics with shoulder dislocations was 2 per cent.

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DISCUSSION

Dr. Chalmers R. Carr, Charlotte, North Carolina: Dr. Rowe's figures tend to prove that the Bankart is the better procedure. The Bankart operation was performed in a far greater number of patients. One can hardly compare it statistically with other operations. Adams found in a group more capable statistically of comparison that there was little to choose from between the Bankart operation and the so-called Putti-Platt type of procedure. The use of either resulted successfully in 95 per cent of the patients.

Dr. Rowe has established essentially normal motion as the criterion for an excellent result. It was H. Osmond Clarke who felt that successful treatment depends upon limitation of external rotation and Adams who commented that there was no doubt that this restriction of movement is the price paid willingly for stability and full confidence in the shoulder. I wish to emphasize that completely normal scapulohumeral motion should not be the requirement for an excellent result.

Recurrent Ulnar-Nerve Dislocation at the Elbow*

BY HAROLD M. CHILDRESS, M.D., JAMESTOWN, NEW YORK

The medical literature is unusually contradictory as to the etiology, incidence, treatment, and even prognosis of recurrent dislocation of the ulnar nerve. Dislocation occurs when the nerve moves out of the postcondylar groove onto or across the tip of the medial humeral epicondyle when the elbow is flexed, returning to its normal location when the elbow is extended. Opinions differ, but most investigators believe that complete displacement of the nerve is exceptional and that it is usually followed by friction neuritis. The purposes of this paper are to show that such hypermobility is not uncommon, that an associated neuritis, although relatively rare, may be of serious consequence, and that, in many instances, ulnar neuritis could have been avoided had the patient and his physician known that such an anomaly was present. Emphasis is also made that the diagnosis is frequently missed because the patient's complaints are often at the hand and not at the elbow.

This report is based upon the observation and treatment of thirty-four patients with ulnar neuritis due, directly or indirectly, to excessive nerve mobility. Seven of the patients required surgical transplantation. In addition, examinations were made of 2,000 supposedly normal ulnar nerves in 1,000 selected individuals.

There is disagreement concerning the etiology of this anomaly. Cobb is of the opinion that the dislocation may be caused by an hypertrophy of the medial fibers of the triceps muscle which pushes the nerve from its bed. Arkin reported a dislocation caused by direct trauma and concluded that the fascia overlying the postcondylar groove had ruptured. Burman and Sutro claimed that a congenital posterior malposition of the medial epicondyle is a predisposing condition. According to this premise, the nerve must traverse a longer-than-normal course during elbow flexion, and it dislocates at a certain point in order to relieve the abnormal tension. Platt offered as possible explanations (1) variation in depth of groove, (2) congenital or acquired laxity of the arcuate ligament, and (3) an exaggerated carrying angle. Richards agreed that cubitus valgus is a factor, when it is associated with hyperextensibility of the elbow joint. Haim suggested that cubitus varus is the cause of dislocation.

The reported incidence of habitual ulnar-nerve dislocation has been variable. Collinet found fifteen instances (3.3 per cent) in 500 persons. Burman and Sutro noted the anomaly eleven times (13.8 per cent) in eighty patients. Momburg discovered twenty-three instances (19.8 per cent) in 140 soldiers. Dubs, however, collected statistics of other writers and found the incidence only 2 per cent in 2,000 patients examined. In our series of 1,000 persons the incidence was 16.2 per cent.

According to Mercer, prognosis in recurring dislocation is poor and usually results in neuritis with pain and weakness at the elbow and hand. Shands points out that occasionally there is actual slipping of the nerve trunk anterior to the medial epicondyle with each flexion of the elbow, which produces a typical friction neuritis. Platt says that a hypermobile nerve may pass unnoticed for years until a complete dislocation occurs, and then frequent repetition of the dislocation causes traumatic neuritis. If the patient is engaged in manual labor, Platt advises a surgical transplantation of the ulnar nerve to the anterior portion of the elbow. Both Richards and Conway believe that such nerves are almost certain to undergo intraneural changes.

In order to test the validity of this medical opinion, the author, himself possessing

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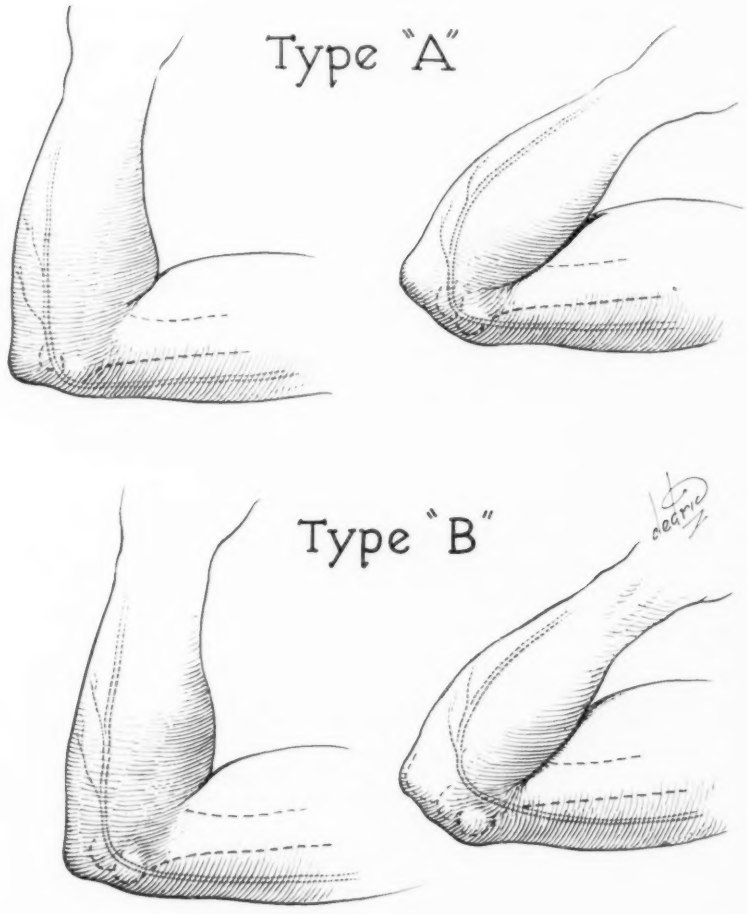

FIG. 1

Drawings show types of dislocation—incomplete (Type A) and complete (Type B).

two such dislocating ulnar nerves, decided to examine 1,000 individuals with ostensibly normal elbows. Fifty normal children were selected; fifty children of the same age group with various unrelated congenital defects; 100 male athletes (professional boxers, wrestlers, and baseball players); fifty female athletes (mostly tennis players and golfers); 300 soldiers; 250 adult patients seen in orthopaedic clinics; and 200 nurses, medical students, and physicians. In this group, 500 were female and 500 male. Early in the study, it became apparent that the degrees of nerve hypermobility could be placed in two classifications, Type A, in which the nerve moves out of its postcondylar groove onto the tip of the humeral epicondyle when the elbow is completely flexed, and Type B, in which the nerve has greater excursion than in Type A, and passes completely across and anterior to the epicondyle when the elbow is flexed to more than 90 degrees (Fig. 1).

Briefly, the results of this survey were as follows: the incidence was 162 in 1,000 subjects (16.2 per cent) with 121 subjects proving to be Type A and forty-one Type B. Of the fourteen unilateral cases, thirteen were Type A with eight ulnar-nerve dislocations occurring on the left elbow although all were right-handed. There were eighty-seven

positive subjects in 500 females (17.4 per cent), and seventy-five in 500 males (15 per cent). The condition was not found to occur more frequently in children with unrelated congenital defects or in athletes of either sex.

As to etiology, no pattern was found in the affected persons. In ten patients affected bilaterally and six patients affected unilaterally, roentgenograms were made of both elbows. Careful measurements were made of the distance of the epicondyles from the olecranon in all the subjects, and the carrying angle was estimated. In no patient could a mechanical reason be found which might be responsible for the dislocation. In the patients affected unilaterally, roentgenograms of the two elbows were indistinguishable and the clinical measurements were the same. No two cases were found in one family. The condition is nearly always bilateral. It is found as often in inactive as in active persons, and it occurs in children. The author considers that the origin of the anomaly is probably congenital. It appears to be due to a congenital "loose anchorage" of the ulnar nerve, and the greater nerve excursion almost always is at the elbow which is used the most.

It was interesting to note that not one of these 162 persons with dislocating ulnar nerves knew that he had such an anomaly. One may conclude from this that an asymptomatic dislocating ulnar nerve is likely to remain quiescent unless subjected to direct or indirect trauma.

A normally situated ulnar nerve at the elbow occupies a position of vulnerability, but a hypermobile ulnar nerve is considerably more exposed to injury. It was our theory that Type A ulnar nerves would be found to be more subject to direct trauma than the Type B nerves; and Type B ulnar structures, possessing greater mobility, would be found to be more susceptible to friction neuritis than Type A structures. This theory was borne out clinically.

A total of thirty-four patients in our study were found to have definite ulnar neuritis due to habitual dislocation of this structure. The precipitating factors were varied. Seventeen were caused by industrial occupations; six by falls and accidents, five by abduction shoulder splints. Incidents occurring on operating-tables accounted for four; one had suffered a shrapnel wound; and a ganglion at the condylar groove caused another.

The following case histories illustrate typical examples of ulnar neuritis due to hypermobility.

CASE REPORTS

Case 1. A female sailmaker, twenty-six years of age, three months previous to examination had a feeling of weakness and numbness at the left wrist and hand. The left elbow joint was continuously brought into complete flexion during her working hours. Her left hand had become somewhat smaller. She had received physical therapy and had been given oral medication. Examination revealed Type B dislocating ulnar nerves at both elbows; the left elbow was enlarged and tender on pressure. In the course of the examination, she complained of severe sharp pain along the nerve when it slipped beneath the examining finger during elbow flexion and extension. There was mild atrophy of the interossei of the hand with hypo-aesthesia at the ulnar distribution. Surgery was recommended, and the nerve was found to be enlarged and hyperaemic. Anterior transplantation was done. Immediate sensory improvement was noted and when last examined, two years later, she had recovered completely. The hypermobile nerve at the right elbow remained asymptomatic.

Case 2. A female factory worker, twenty-four years old, six months before examination had struck the medial aspect of the right wrist against a machine. Her work in the local woolen mill required constant flexing of the elbows. Resulting hand and wrist complaints were treated by multiple intravenous and subcutaneous injections, local novocain infiltration, and several weeks of plaster immobilization which was followed by the wearing of a heavy leather wrist cuff. No relief was obtained. She complained of paraesthesia at the ulnar-nerve distribution of her hand, and inability to use her fingers normally. Examination of the hand revealed definite hypo-aesthesia in this region with moderate atrophy of the intrinsic muscles. Type B dislocating nerves were found at both elbows with considerable enlargement of the ulnar nerve on the right. When she was told that the condition was actually at the elbow and not at the hand and wrist, she was quite disturbed and requested a neurosurgical consultation. She was examined by Dr. F. V. Gieb of Rochester, New York, who confirmed the diagnosis of friction neuritis due to recurring dislocation. At surgery, the nerve was found to be definitely enlarged and hardened, and was fusiform in shape over an area of about

three centimeters. Neurolysis was performed and the nerve was transplanted. Sensation was immediately improved, but the muscle atrophy persisted for several months. When last examined, thirteen months later, she had completely recovered and was working regularly.

Both of these patients had Type B dislocating ulnar nerves with definite friction neuritis. Excellent results were obtained by anterior transplantation. In both cases, early diagnosis and prescribed limited use of the affected elbow might have allowed the irritation to subside, thus avoiding surgery. Certainly, in Case 2, a correct diagnosis at the beginning of the trouble would have eliminated six months of misdirected treatment. Shortly after examining Case 2, Dr. Gieb had another industrial patient with an almost identical condition. This patient was also treated successfully by transplantation of the nerve.

CASE 3. A soldier, thirty-four years old, examined at Stark General Hospital, had three months previously been subjected to a thirty-minute knee operation while under general anaesthesia. Immediately after surgery, he complained of numbness at the medial portion of the right hand followed within a few days by definite weakness of the grip. He insisted that his disability was due to the carelessness of the operating-room personnel. Examination revealed Type A ulnar-nerve hypermobility at both elbows with tenderness upon pressure, and enlargement of the left ulnar nerve. There was moderate atrophy of the interossei, with hypo-aesthesia over the ulnar sensory field. On surgical exposure of the nerve, it was found to be hyperaemic and definitely enlarged. Neurolysis was considered necessary before transplantation was done. Improvement was gradual but definite, and he was returned to duty in four weeks. He still complained of paraesthesia at the hand when last heard from five months later.

Three other patients suffering from similar operating-table trauma were seen; none of them, however, required surgery. In each instance, the nerve had been trapped on top of the epicondyle when the medial aspect of the flexed elbow had rested on the sharp edge of the operating table during surgery. This pressure, continued for a period of time, produced intraneural changes. All of these patients complained of paraesthesia for many months both before and after examination. Normally located ulnar nerves may also be injured by careless positioning of a patient's elbows when he is under general anaesthesia.

CASE 4. An orthopaedic surgeon, forty-eight years old, complained of the sudden occurrence of pain at the left elbow and a tingling sensation over the medial side of the hand while driving his car. The medial portion of his elbow was supported by the elbow rest, and when the elbow was jarred by the action of the car, a trigger mechanism was released and the elbow suddenly and involuntarily straightened. The patient remembered that the day before he had practiced a new exercise for twenty minutes—striking a pneumatic punching bag with the medial sides of the elbows while these joints were in complete flexion. Examination revealed marked sensitivity at the left ulnar nerve at the elbow and Type A mobility. Percussion of the nerve caused a sharp pain to radiate down the medial aspect of the forearm and an uncontrolled jerking of the elbow. There was slightly diminished sensation over the ulnar distribution at the hand, but no muscle atrophy was noted. The hypermobile right ulnar nerve was Type B, but was not symptomatic. Both of these nerves had been subjected to the same type and degree of trauma during the exercise. The nerve on the right, which had greater mobility, had slipped to safety anterior to the epicondyle, whereas the ulnar nerve at the left elbow, being stretched across the tip of the epicondyle at complete elbow flexion, had received the full force of the blows. Sensation at the hand returned to normal in ten days, but the nerve remained acutely sensitive to pressure for the next six weeks. This patient was aware of having such anomalies, and recalled that the Type A ulnar nerve at the left elbow had been injured before repeatedly, but the Type B ulnar nerve at the right elbow had always been asymptomatic, except on one occasion when it was examined rather vigorously by a group of medical students during a demonstration of recurrent ulnar-nerve displacement.

Eighteen physicians were found to have this anomaly but not one was aware of its presence. Love mentioned that one of his patients who required transplantation for ulnar neuritis, due to habitual dislocation, was a neurosurgeon.

CASE 5. A female inspector in a factory, twenty-six years old, two months before examination noticed vague sensory changes at the left hand and inability to use the hand normally. At her work, she constantly wrote on a wall desk at shoulder level. She habitually rested the flexed left elbow on the desk surface while writing. There had been mild intermittent pain at the elbow for which she had received various types of treatment, including whirlpool therapy and intravenous injections, but without benefit. At examination, Type A

dislocating ulnar nerves were found at both elbows, with increased sensitivity to pressure at the left elbow. No sensory changes were noted, but a mild atrophy of the intrinsic muscles was apparent. The cause of her complaints was explained to her, and at the factory she asked to be shifted to another type of work. This was done; the irritation at the hypermobile nerve subsided, and she recovered without further treatment.

When examined, industrial workers invariably describe accidental injuries on the job to explain or justify their complaints. In the majority of these cases, however, the alleged trauma was sustained at the medial side of the hand and wrist, not at the elbow. With most of the cases, the highly mobile Type B ulnar nerve was usually subjected to mild repeated trauma in the course of their work. The constant passage of the injured nerve across the epicondyle produces a perineural irritation which causes numbness and weakness at the hand. A definite neuroma may develop if the irritation is untreated but if the condition is diagnosed promptly the reaction usually subsides upon limitation of elbow usage.

Severe injury to the elbow is common in falls or automobile accidents. Six patients were encountered with neuritis due to direct trauma to the medial portion of the flexed elbow; two of them required surgical nerve transfer. The traumatized tissues react to continual ulnar-nerve displacement by a constricting scar formation, with or without overgrowth of the nerve sheath.

Abduction shoulder appliances and plaster spicas are potential dangers to this displaced nerve, particularly the Type A structure. The first patient seen in this series was partly paralyzed following the application of a postoperative shoulder plaster spica, while under general anaesthesia. Upon regaining full consciousness, she became aware of a numbness at the medial portion of the hand. A window was cut out of the cast over the medial portion of the elbow, and the ulnar nerve was found to be compressed and lying across the apex of the epicondyle. It is possible to detect and relieve this type of pressure immediately in patients who are conscious when such splints or spicas are applied. If, however, the patient is under anaesthesia or heavy narcosis for severe pain at the arm and shoulder, the nerve may be severely traumatized before complaint is made and the condition is recognized. Slightly changing the elbow flexion in the cast allows the nerve to slip to a position of safety, anterior or posterior to the epicondyle. Of the five patients with this type of dislocation, all recovered without surgery.

Surgery is indicated for those patients with definite friction neuritis associated with progressive sensory and motor loss. Although several orthopaedic textbooks describe only the subcutaneous method for ulnar-nerve transplantation, the trend is definitely toward the deep procedure. McGowan reported six cases of unsuccessful ulnar-nerve transfers which were relieved by re-operation with deep implantation. Gay and Love transplanted deeply ninety-five of ninety-nine nerves so treated. They reported one patient, a physician, who had had three unsuccessful subcutaneous repositionings of the nerve, and who made an excellent recovery following neurolysis and intramuscular placement. Unsatisfactory results following shallow transplantation are not rare, and apparently are due to the return of the ulnar nerve to its original groove or to constriction by the sutures or fascial strips.

SURGICAL TECHNIQUE

A curved ten-centimeter incision is made anterior to the course of the ulnar nerve at the medial aspect of the elbow. After the fascia has been excised over the postcondylar groove, the nerve is mobilized freely at both ends. The nerve's small sensory branch to the joint is sacrificed, but all motor branches are preserved. The sharp edge of the medial intramuscular septum above the elbow must be removed so that the nerve may be brought over a smooth surface. The fascia is excised two centimeters distal to the epicondyle, and a channel is made in the proximal flexor muscle group extending down between the heads of the flexor carpi ulnaris (Fig. 2). Before closure of the wound, the nerve should be

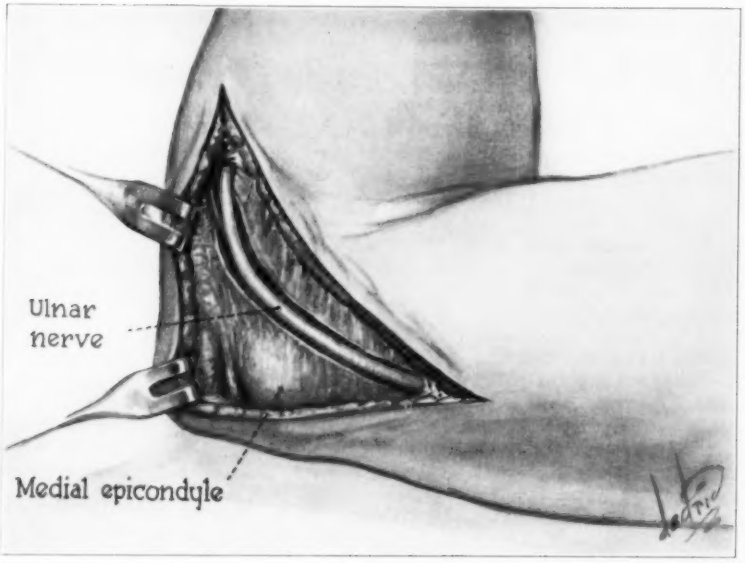

FIG. 2

Illustrating intramuscular transplantation of the ulnar nerve.

observed in its new bed while the elbow is flexed and extended, to be certain that no kinking is present. Postoperative immobilization for two weeks with the elbow in 90 degrees flexion is obtained by a plaster casing.

CONCLUSIONS

1. In a survey of 2,000 supposedly normal elbows, recurrent dislocation of the ulnar nerve was found in 16.2 percent of the subjects. It occurs slightly more often in females than in males.

2. The probable cause of recurrent dislocation is congenital laxity of supporting ligaments.

3. Such nerves usually remain asymptomatic unless they are subjected to trauma; friction neuritis may develop as a result of trauma.

4. Hypermobility is classified into Type A (incomplete dislocation of the ulnar nerve) and Type B (complete dislocation of the ulnar nerve).

5. Observation of thirty-four cases of ulnar neuritis due to dislocation indicates that Type A ulnar nerves are subject to direct trauma, whereas Type B ulnar nerves are more vulnerable to friction irritation.

6. Industrial workers are more often affected than other people and their complaints are usually at the hand and not at the elbow.

7. Unnecessary and prolonged treatment could be avoided by a correct early diagnosis and by informing the patient of his anomaly.

8. In anterior transplantation, deep intramuscular placement of the nerve is superior to the subcutaneous method.

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DISCUSSION

Dr. Benjamin E. Obletz, Buffalo, New York: Dr. Childress has presented us with a very interesting paper. He has found that many people have dislocating ulnar nerves. I find that I have two such dislocating nerves myself. I was not aware of them until I examined my elbows after reading Dr. Childress' paper. Several of my colleagues discovered similar asymptomatic dislocations in themselves. An orthopaedist in our group found that he has two nerves which completely dislocate, and now he can understand the numbness and tingling in the fingers on the ulnar side when he sleeps lying face down with his arms over his head and his elbows flexed. I am certain that many men in this audience can find similar dislocating nerves in their own elbows.

What causes these dislocating nerves in otherwise normal elbows? In my opinion, it is possible that the basic factor lies in the anatomy of the medial condyle of the humerus. If the ulnar groove is deep and has an overhanging edge, the nerve should be secure against dislocation. If there is no distinct groove for the ulnar nerve, or if the condyle slopes away from the trochlea, some degree of dislocation can occur when the elbow is flexed. I do not know of a ligament which stabilizes the nerve under the condyle.

Dr. Childress reports that he has seven times performed a transposition of the ulnar nerve anteriorly. I wonder if he observed anything during the surgery which can explain the recurrent dislocations?

Dr. James E. Bateman, Toronto, Ontario, Canada: Dr. Childress has presented a meticulous and scientific study of a most interesting lesion. I am sure that insufficient attention has been paid to this condition in the past.

Trauma appears to be the precipitating cause which most frequently brings this lesion into clinical focus. However, there is a very considerable difference in persons as to size, shape, and depth of the ulnar groove, and hence a correspondingly variable degree to which the nerve is exposed to trauma.

In these cases, one wonders which comes first, the neuritis or the dislocation. Injury or repetitive trauma produces swelling and neuroma formation, and leaves a thickened, folded nerve which may easily roll out of the groove. Or does the nerve slip for a reason we do not know, leading to the typical changes resulting from the friction action?

[In support of the role which injury plays in this condition, a slide was shown which demonstrated his experience with the process.] The patient bumped his elbow several months before this roentgenogram was made, and the typical signs developed of ulnar-nerve irritation, partial paralysis, and an easily displaced or dislocating ulnar nerve. At operation a small detached flake from the ulnar nerve was removed from the center of the ulnar groove. After anterior transplantation, the patient made a satisfactory recovery.

I feel that the incidence of displacement, as presented, is a little high.

Dr. Childress (closing): I wish to thank Dr. Bateman and Dr. Obletz for their remarks. In reply to Dr. Bateman's question concerning the incidence of this condition, I would like to say that the figures of

(Continued on page 1055)

Chronic Neurological Sequelae of Acute Trauma to the Spine and Spinal Cord*

Part I

The Significance of the Acute-Flexion or "Tear-Drop" Fracture-Dislocation of the Cervical Spine

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Certain chronic neurological sequelae to be described may result not uncommonly from an isolated acute injury to the spine and spinal cord. Often this neurological pattern may arise from repeated minor traumatic insults to the spinal cord and develop so insidiously that a diagnosis is made of chronic degenerative disease of the spinal cord. Early recognition and verification of the lesion which is responsible is important so that proper corrective measures can be instituted before irreversible neuro-anatomical changes occur.

The lesions involved include those caused by fracture-dislocations, compression fractures, undebrided penetrating wounds of the spine with retained foreign bodies, herniated intervertebral discs, and chronic hyperextension injuries of the spine. Since such a discussion is too extensive for one paper, it has seemed advisable to divide the material into two reports on the basis of etiology. Part I concerns one of the causes of this syndrome, the acute-flexion or "tear-drop" fracture-dislocation. Part II will include the remaining types of causative lesions noted above. The sequelae of the acute-flexion or tear-drop fracture-dislocation are probably best illustrated by case reports.

THE SIGNIFICANCE OF THE ACUTE-FLEXION OR TEAR-DROP FRACTURE-DISLOCATION

Among the acute injuries of the cervical spine, the acute-flexion, tear-drop type of fracture-dislocation has received only scant attention. This lesion is characterized by crushing of one vertebral body by the vertebral body superior to it in such a manner that the anterior part of the involved centrum is not only compressed but often is completely broken away from its major portion (Fig. 1). In most of these cases, this fragment has resembled a drop of water dripping from the vertebral body and it has been associated with dire circumstances so frequently that the terms "tear-drop" and "acute-flexion" fracture-dislocation of the cervical spine seemed to describe the lesion and to suggest the mechanism of the injury. The most important feature of this injury is the displacement of the inferior margin of the fractured vertebral body backward into the spinal canal, which often causes compression or destruction of the anterior portion of the cervical spinal cord. Recognition of this lesion is important from the standpoint of treating the immediate sequelae of the initial injury and for the prevention of a chronic neurological deficit which may occur years after the traumatic episode if proper treatment is neglected.

In 1951, one of the authors (R. C. S.) described a syndrome in acute injuries of the cervical spinal cord for which early operation was advocated [6]. In the past year, a more comprehensive review of this problem was presented under the title "The Syndrome of Acute Anterior Spinal Cord Injury".[7] This syndrome is characterized by immediate complete motor paralysis, hypo-aesthesia and hypo-algesia to a level consistent with the lesion, preservation of the sense of motion and sense of position but partial loss of the sense

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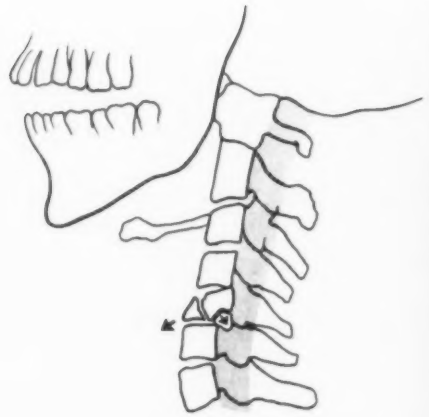

FIG. 1

Fig. 1: Diagram of acute-flexion or tear-drop fracture-dislocation. The body of the involved vertebra is compressed and the anterior inferior fragment is displaced downward and forward. The posterior inferior portion projects posteriorly into the cervical spinal canal.

FIG. 2-A

Fig. 2-A: Case 1. A typical acute-flexion or tear-drop fracture-dislocation of the fourth cervical vertebra in a seventeen-year-old tumbler. (Reproduced by permission from the *Journal of Neurosurgery*, **12**: 103, 1955.)

of touch and vibration. This neurological pattern was found in cases of acute injury to the cervical spinal cord associated with destruction or compression of the anterior portion of the cord by extruded intervertebral discs, compression fractures, and fracture-dislocations. When compression was a factor, the production of this syndrome was believed to be an acute phase of the syndrome of chronic compression caused by calcified lesions lying anterior to the cord. This was described by one of the authors [4] and will be discussed.

Recognition of the syndrome caused by acute injury of the anterior portion of the cervical spinal cord is important. It is impossible to distinguish between compression and destruction of this portion of the cervical spinal cord without surgery, therefore early laminectomy is advisable with sectioning of the dentate ligaments at several levels to decompress the cord and to enable exploration anterior to it in order to determine if a lesion amenable to surgical treatment is present.

The roentgenograms and case reports of two of the twelve patients with injury to the anterior portion of the cervical spinal cord which were previously published are reprinted here to show the similarity of the fracture-dislocations and to demonstrate their important role in the syndrome of the acute injury to the anterior portions of the cervical spinal cord (Cases 1 and 2, Figs. 2-A through 3-C).

In one of the patients the injury to the cervical spine resulted in a compression fracture of the centrum of the fifth cervical vertebra with posterior displacement of the entire vertebra but without avulsion of the anterior portion. With more force, separation of the fractured anterior portion undoubtedly would have occurred.

Fig. 2-B: The cervical roentgenogram made two and one-half years after injury demonstrates apparent fusion between the fourth and fifth cervical vertebrae with a posterior bony protrusion projecting into the cervical spinal canal. Compare with Fig. 2-A, which was made after the initial injury. (Reproduced by permission of the *Journal of Neurosurgery*, **12**: 103, 1955.)

Figs. 2-C and 2-D: Myelograms indicate marked encroachment on the spinal canal by a bony overgrowth at the interspace between the fourth and fifth cervical vertebrae. (Reproduced by permission of the *Journal of Neurosurgery*, **12**: 104, 1955.)

Fig. 2-D

Fig. 2-C

Fig. 2-B

This boy had been placed in traction at another institution for six weeks without recovering motor function; he was then referred to University Hospital merely for physical rehabilitation. When the syndrome of acute injury to the anterior portion of the cervical spinal cord was recognized on admission, decompressive laminectomy was performed with section of the dentate ligaments. Within twenty-four to thirty-six hours he began to move his fingers and toes. This improvement may have been purely coincidental, but it suggests that the surgical intervention may have been of some value.

The problems associated with the acute flexion or tear-drop fracture-dislocation are not completely resolved by laminectomy and section of the dentate ligaments to decompress the spinal cord. Subsequent spine fusion is frequently indicated to prevent the sequelae of chronic compression of the anterior portion of the cervical spinal cord.

The following cases are presented as illustrations:

Case 1. M. S., a seventeen-year-old tumbler, fell March 29, 1951, striking on the vertex of his head. Complete paralysis resulted in all four extremities, except for equivocal movement of his right great toe. There was headache, pain in the neck, and numbness from the neck downward over the trunk and extremities.

Upon admission to a Detroit Hospital there was hypo-aesthesia and hypo-algesia to the level of the fourth cervical dermatome, but the sense of position and the sense of touch were preserved bilaterally throughout the entire body. There was complete motor paralysis in both lower extremities. The patient could move his arms at the shoulders and extend his wrists but he had no active motion in any of his fingers. There was generalized hyporeflexia with no extensor plantar reflexes.

Roentgenograms of the cervical spine revealed a compression fracture-dislocation of the body of the fourth cervical vertebra with a 30 per cent collapse in its vertical height (Fig. 2-A). The vertebra was posteriorly displaced three to four millimeters.

Crutchfield tongs were applied and an indwelling catheter was inserted. On March 31, 1951, a lumbar puncture was performed and on jugular compression there was an equivocal partial block to the flow of cerebrospinal fluid. The cerebrospinal-fluid protein was 63 milligrams per 100 milliliters. On April 14, 1951, a second lumbar puncture revealed similar cerebrospinal-fluid dynamics. At this time the cerebrospinal-fluid protein was 110 milligrams per 100 milliliters.

Three and one-half weeks after injury the level of hypo-algesia and hypo-aesthesia was gradually receding; there was recovery of motion in the lower extremities and the patient was able to flex the fingers of both hands. A plaster body jacket was applied on April 27, 1951, and, on June 14, a back brace replaced this appliance. On August 3, 1951, it was discovered that the level of hypo-algesia and hypo-aesthesia, which had receded to the first lumbar dermatome, had risen again to the eighth thoracic dermatome. There was a wrist-drop on the left and foot-drop on the right. Bilateral extensor plantar reflexes and ankle clonus were elicited. Bladder control and bowel function were good.

As a student at the University of Michigan, he was under frequent neurosurgical observation. By August 1953, he began to have increasing spasticity in the lower extremities and was admitted to University Hospital for studies. Roentgenograms of the cervical spine are shown (Fig. 2-B). A cervical myelogram, made September 1, 1953, demonstrated a marked compression of the anterior portion of the cord (Figs. 2-C and 2-D).

At the time of the decompression laminectomy on September 2, 1953, the spine was extremely unstable. The laminae of the fourth and fifth cervical vertebrae, which had been fractured bilaterally, were healed but they were thin and osteoporotic. These laminae were removed bilaterally with a portion of the lamina of the third cervical vertebra. The dura mater was incised in the mid-line, and the very weak dentate ligaments were sectioned at two levels. At the interspace between the fourth and fifth cervical vertebrae there was a central bony protrusion, three to four millimeters in height, which could not be chiseled away for fear of injuring the ribbon-thin cord. The dura mater was left open, the cerebrospinal fluid being contained by the intact arachnoid membrane.

Inverted V-shaped bone grafts were inserted bilaterally from the spinous process of the third to the sixth cervical vertebrae. The wound was closed in layers.

Postoperatively the patient was able to walk with the aid of a cane and a spring kick-up brace. There were spotty areas of hypo-aesthesia and hypo-algesia extending to the level of the dermatome of the tenth thoracic-nerve root on the right side. Temperature sense was not clearly defined over the lower extremities, particularly on the right side. The sense of motion and the sense of position were intact bilaterally. Pyramidal-tract signs were present bilaterally with increased tonus in the upper and lower extremities; ankle clonus and the Babinski sign were present bilaterally. The patient's condition has continued to improve; the degree of spasticity present preoperatively has diminished somewhat, and the patient is able to attend college again.

This patient had a typical syndrome of acute injury to the anterior portion of the cervical spinal cord combined with the acute-flexion or tear-drop vertebral fracture-

dislocation. It is particularly interesting to note that the jugular-compression test did not reveal a complete subarachnoid block on two occasions, five days apart, and yet cerebrospinal fluid protein was definitely elevated at the first test and had increased by the time of the second lumbar puncture, five days later, although there was no blood in the specimen. This would suggest irritation of the spinal cord, possibly caused by bony pressure upon the oedematous anterior surface of the cord, and shows that an elevated cerebrospinal-fluid protein may be present even when the patient does not have a complete subarachnoid block or hemorrhage. Perhaps increase of the cerebrospinal-fluid protein merely indicates contusion of the spinal cord, but in that case the protein level should not have become progressively elevated. Although the patient showed a remarkable improvement at first, his condition began to deteriorate one and one-half years after injury and he had increasing spasticity. Because of the degree of narrowing of the cervical-spine canal, myelography was extremely dangerous. In retrospect, the patient should have been operated upon as soon after injury as his condition permitted and then, either primarily or secondarily, have had a spinal fusion.

FIG. 3-A

Case 2. A tear-drop lesion of the fourth cervical vertebra in a sixteen-year-old tumbler. (Reproduced by permission from the *Journal of Neurosurgery*, **12**: 101, 1955.)

CASE 2. H. P., a sixteen-year-old tumbler, sustained a severe injury to the cervical spine on May 14, 1948. According to the patient he suffered immediate complete motor paralysis of all four extremities with loss of sensation below the neck. Roentgenograms of the cervical spine revealed a compression fracture-dislocation of the fourth cervical vertebra and minimal posterior dislocation of the fourth cervical vertebra with relation to the fifth (Fig. 3-A).

Approximately twelve hours after injury, he was transferred to University Hospital. Areflexia and tetraplegia were confirmed by clinical examination, and hypo-algesia and hypo-anaesthesia were present to the level of the dermatome of the fourth cervical-nerve root. A lumbar puncture and jugular-compression test revealed an incomplete subarachnoid block.

As there was no progression of signs and only a partial block on the jugular-compression test, the patient was not operated upon. However, no improvement occurred during the next four years.

The patient was re-admitted to the University Hospital four years after injury, because of involuntary contractions of the fingers. Hypo-algesia and thermanaesthesia were present bilaterally to the level of the dermatome of the sixth thoracic-nerve root, and hypo-anaesthesia was found to the level of the sixth cervical-nerve root bilaterally. The sense of motion and sense of position were present throughout the body and the sense of vibration was present except over the right lateral malleolus. The sense of touch was present everywhere except in the left lower extremity where responses to touch were irregular. There was generalized spasticity and hyperreflexia in all extremities. Frequent spasms caused the legs to be extended rigidly, and hyperreflexia of the fingers caused them to be contracted into fists. Occasionally the patient's spasms were sufficiently severe to precipitate him out of bed onto the floor. Clonus of both wrists and of the patella on the left side was elicited.

Roentgenograms of the cervical vertebrae at this time revealed a loss of the interspaces between the third and fourth and between the fourth and fifth cervical vertebrae. There was posterior displacement of the fourth cervical vertebra on the fifth, and the third cervical vertebra had apparently fused in a position of slight anterior displacement on the fourth cervical vertebra (Fig. 3-B).

Lumbar puncture showed no subarachnoid block, but cervical myelograms revealed mid-line defects at the interspaces between the third and fourth and between the fourth and fifth cervical vertebrae (Fig. 3-C). After the myelography, the sense of motion, the sense of position, and the sense of vibration were further impaired.

On May 19, 1952, a laminectomy was performed from the third cervical vertebra through the sixth.

FIG. 3-B

FIG. 3-C

Fig. 3-B: The lateral cervical roentgenogram four years later showing loss of the interspaces between the third and fourth and fourth and fifth cervical vertebrae with projection of bone posteriorly into the spinal canal. (Reproduced by permission of the *Journal of Neurosurgery*, **12**: 101, 1955.)

Fig. 3-C: The cervical myelogram shows mid-line filling defects at the sites of bony overgrowth. (Reproduced by permission from the *Journal of Neurosurgery*, **12**: 101, 1955.)

Although the roentgenograms had demonstrated what appeared to be fusion of the third and fourth cervical vertebrae *marked* instability of both the third and fourth cervical vertebrae and no evidence of fracture were found at operation.

There were marked adhesions between the arachnoid membrane and the dura mater laterally at the interspace between the fourth and fifth cervical vertebrae. After cutting the dentate ligaments bilaterally at four levels, gentle retraction of the cord revealed the bony projection demonstrated on the roentgenograms. No herniated disc material could be found. There was a definite variation in the levels of the insertion of the dentate ligaments, the spinal cord being displaced more posteriorly at the levels of the interspaces between the third and fourth and between the fourth and fifth cervical vertebrae than at the levels of the other two exposed interspaces. At the end of the procedure the dura mater was sutured and the wound was closed.

Postoperatively the wrist clonus which had been present preoperatively was no longer demonstrable and the tonus in the upper extremities had decreased about 50 per cent; however, the mass reflexes in the lower extremities were slightly accentuated. Finally, in June 1952, an anterior rhizotomy was performed, and the spasms of the lower extremities were adequately controlled. Marked spasticity and clonus were still present in both upper extremities.

When the patient was admitted to the Hospital at the time of injury, he had the syndrome of acute injury to the anterior portion of the cervical cord. There was no progression of signs and only a partial block on the jugular-compression test; consequently the patient was not operated upon. Over a period of four years there had been no regression of symptoms. The cervical exploration should have been performed as soon after injury as the patient's condition permitted. The pronounced instability of the fourth and fifth cervical vertebrae found at operation four years after injury suggests that it is important to perform early fusion of the damaged segments of the cervical spine in these incomplete lesions of the cervical cord. This case also demonstrates that roentgenograms may be misleading in determining stability of the cervical spine. This is a case of the syndrome of the

FIG. 4-A

FIG. 4-B

Fig. 4-A: Case 3. Roentgenogram made in 1947 of an acute-flexion or tear-drop fracture-dislocation.
Fig. 4-B: Roentgenogram of the lesion made eight years later showing spontaneous fusion of the third, fourth, and fifth cervical vertebrae and bony impingement on the anterior surface of the spinal cord.

acute injury to the anterior portion of the cervical spinal cord without complete block, which did not show recovery even after four years.

Another tear-drop fracture-dislocation with persistent spinal instability is demonstrated in the following case:

CASE 3. F. Z., male, twenty-four years old, dove into two feet of water on July 7, 1947. On admission to a local hospital he was not unconscious, he had no respiratory difficulty, and he could speak. He experienced sharp pains in the cervical region upon movement of the neck. There was no motor paralysis of the arms or legs, no difficulty in voiding, and no impairment of sensation. The patient had moderate pain in the left lower extremity.

However, on the following day, there was paralysis of all four extremities and of the bladder and the bowel. The pupil of the right eye was dilated. Roentgenograms of the cervical spine revealed a typical acute-flexion injury, a tear-drop fracture-dislocation (Fig. 4-A). A Thomas collar was applied forty-eight hours after injury. A short time thereafter the patient recovered bowel and bladder control. He continued to improve rapidly so that nine weeks after injury, he was permitted to walk a few steps and was discharged from the hospital on August 27, 1947. For six years, his physical condition continued to be good.

In March 1954, the patient presented himself for examination (while an inmate at the South Michigan Prison). He complained of increasing weakness and "jumping" in the left upper and lower extremities for the past year.

On examination, tenderness was found over the mid-portion of the cervical spine with a slight limitation of hyperextension of the neck. Weakness was present in all muscle group movements of the left upper and lower extremities, the most marked impairment being in the left deltoid muscle. Atrophy of one and one-half inches was demonstrated in the left arm and of one and one-quarter inches in the left forearm. Atrophy of one and one-half inches was present in the left thigh, but the left calf showed no atrophy. Muscle tone was markedly increased in all of the muscles of the left upper and lower extremities. The patient was unable to open and close the left hand quickly. Sustained clonus of the left ankle and wrist was elicited. On the right side hypo-algesia and hypo-thermanaesthesia were present to the level of the dermatome of the fourth

cervical-nerve root. The sense of motion, sense of position, and sense of touch were unimpaired bilaterally. Hyper-reflexia was demonstrated in both lower extremities but was more marked in the left patellar and Achilles-tendon reflexes. The reflexes of the triceps and biceps and the radial periosteal reflex were more active on the left than on the right. An extensor plantar reflex was present bilaterally but this was more marked on the left side. A positive Hoffman sign was elicited on the left side. Roentgenograms of the cervical spine now showed fusion of the third, fourth, and fifth vertebral bodies with almost complete obliteration of the interspaces, a kyphosis and a marked bony overgrowth posteriorly impinging on the cervical spinal canal (Fig. 4-B).

It was the examiner's impression that there was a marked compression of the anterior portion of the spinal cord and that a cervical laminectomy, section of the dentate ligaments, and excision of part of the bony exostosis anterior to the cervical spinal cord should be performed. It was also his opinion that a spine fusion should probably be performed at the same time. Since the patient was to be paroled soon, the operation was to be deferred until after his release.

This patient exhibited the typical acute-flexion or tear-drop fracture-dislocation at the time of his first hospital admission on July 7, 1947. Transient complete tetraplegia developed, probably because of inadequate immobilization. There was a progression of neurological signs which suggested that surgical intervention was indicated. However, after an interval of stabilization in a Thomas collar, spontaneous improvement occurred. Immobilization was incomplete, and although the patient made a good initial recovery, the prognosis now is extremely grave because there is chronic compression of the anterior portion of the cervical spinal cord similar to that noted in Case 1. Early operation with decompression of the spinal cord and either primary or secondary spine fusion might have prevented this.

Case 4. J. W., a retired Navy lieutenant, thirty-six years old, was first seen in consultation on November 1, 1954, because of weakness in his left hand and arm. He complained also of severe pain radiating into all four extremities on merely flexing his neck or on coughing and sneezing.

Twelve years before, during World War II, he was aboard a destroyer which sustained a direct hit. He had been thrown upward, striking his head against a steel beam. Upon falling to the deck, he sustained a severe contused laceration of the left lower extremity and a tear of the cruciate ligaments of the left knee. He jumped from the bridge of the listing destroyer into the water, a distance which he estimated as fifty feet, and had clung to a life raft for eighteen hours under shore fire before being picked up by a friendly vessel.

Aboard a hospital ship, six days after injury, a roentgenogram of the cervical spine showed a severe compression fracture of the body of the fifth cervical vertebra. There was no weakness or numbness of the extremities and no incontinence of the bladder or bowel. A plaster collar was applied for three weeks and then replaced by a neck brace for another three or four weeks.

In November 1953, a year before consultation, he began noting progressive weakness in the finer movements of the left hand and forearm as well as numbness in the left thumb and index finger. In November 1954, he first noticed that when he sneezed or forcibly flexed his neck there was a sharp, shooting pain radiating into all four extremities.

At this time, twelve years after injury, there was tenderness on percussion over the fifth and sixth cervical spinous processes with no radiating pain. There was marked weakness in the grip of the left hand. The interosseus muscles were atrophied and abduction and adduction of the fingers were impaired. The strength of the left biceps muscle was diminished. No weakness was found in the muscles of the right upper extremity and the muscles of both lower extremities had normal strength. Sensation was normal except for hypo-algesia and hypo-anaesthesia in the dermatome of the sixth cervical-nerve root on the left and around the margins of the scar on the left leg and thigh. All reflexes were equal and active except in the left biceps. The remainder of the neurological examination was normal.

Roentgenograms made in 1948, six years after injury, showed a healing compression fracture of the body of the fifth cervical vertebra (Fig. 5-A). Recheck roentgenograms made in 1954, twelve years after injury, revealed an increase in bony overgrowth at the interspace between the fifth and sixth cervical vertebrae (Fig. 5-B).

Review of the roentgenograms suggests the presence of an old, healed tear-drop fracture-dislocation. At the present time there is not only evidence of compression of the cervical-nerve roots at the fracture site, but also a history suggesting chronic compression of the anterior portion of the cervical spinal cord. A cervical myelogram is indicated. It is probable that findings in this test would suggest that laminectomy and decompression of the cervical spinal cord should be performed.

FIG. 5-A

FIG. 5-B

Fig. 5-A. Case 4. Cervical roentgenogram made in 1948 of the cervical spine of a Navy lieutenant injured six years before during World War II. The roentgenogram shows healing of the typical tear-drop fracture-dislocation of the fifth cervical vertebra on the sixth cervical vertebra.
Fig. 5-B: Roentgenogram of the same lesion twelve years after the injury.

CASE 5. J. S., a nineteen-year-old male, dived into shallow water on July 1, 1954. He sustained a scalp laceration and was rendered unconscious for a brief interval. There was no numbness or paralysis of the extremities. Roentgenograms of the cervical spine demonstrated an acute-flexion or tear-drop fracture-dislocation of the fourth cervical vertebra on the fifth (Fig. 6-A). Three days after the application of skeletal traction by Crutchfield tongs, there was marked improvement in the alignment of the cervical spine (Fig. 6-B). Unfortunately, after four weeks, the skeletal traction had to be discontinued because one of the tong points had penetrated the brain in the left posterior parietal area. This had caused a Jacksonian seizure on the right side which had its onset in the right arm. Fixation in a plaster cast replaced the cervical traction and, after two months, the cast was replaced by a Forrester collar for a period of three months.

Six months after the injury, the patient was examined at University Hospital because of recurring episodes of numbness in both hands for intervals of five minutes. These symptoms appeared when the patient was in the sitting position and were apparently confined to the areas in the hand innervated by the median nerve. Recheck roentgenograms of the cervical spine revealed telescoping of the body of the fifth cervical vertebra into that of the sixth with encroachment on the anterior portion of the cervical spinal canal (Fig. 6-C). On December 17, 1954, a myelogram showed a mid-line filling defect at the level of the fifth and six cervical vertebrae. Skeletal traction by Vinke tongs was begun on December 24, 1954, and three days later a laminectomy of the fifth and sixth cervical vertebrae was performed. The dura mater was incised and the dentate ligaments were cut. No bony protrusion was noted anterior to the spinal cord, but this was probably due to the fact that during the operation the traction was applied so that the patient's neck was maintained in the plane of the body rather than in flexion. The dura mater was closed and the spine was fused from the fourth to the seventh cervical vertebra with an autogenous-bone graft removed from the right ilium (Fig. 6-D). A wound infection developed postoperatively, but this was cleared up readily after incision and drainage and antibiotic therapy.

The patient was last examined on February 8, 1955, when he was found to be asymptomatic with no abnormal neurological signs.

Study of the serial roentgenograms suggests that the best time for spine fusion would have been shortly after the injury when the cervical spine was in fairly satisfactory align-

Fig. 6-C

Fig. 6-B

Fig. 6-A

Fig. 6-A: Case 5. Cervical roentgenogram exhibiting initial lesion and dislocation of the sixth vertebral body on the seventh cervical vertebra in a nineteen-year-old diver.

Fig. 6-B: Roentgenogram made after three days of skeletal traction.

Fig. 6-C: Roentgenogram of the lesion six months after injury. Inadequate fixation permitted redislocation and the formation of a bony overgrowth which encroached on the spinal canal.

Fig. 6-D: Cervical roentgenogram made after partial reduction with skeletal traction, laminectomy of the fifth and sixth cervical vertebrae, section of the dentate ligaments, and spine fusion of the spinous processes and facets of the fourth cervical vertebra to the seventh.

FIG. 6-D

ment as the result of traction. The improper stabilization of the spine, which permitted movement for six months after injury, allowed telescoping of the vertebral bodies and was responsible for the creation of the hyperostosis anterior to the cervical spinal cord as visualized in the roentgenogram. This might eventually have led to chronic compression of the anterior portion of the cervical spinal cord. It was hoped that the application of traction preoperatively with re-alignment of the spine and a spine fusion would prevent future disability. A more complete reduction prior to spine fusion would have been desirable.

Since there were no abnormal neurological findings in this patient, spine fusion alone would probably have been adequate without prior laminectomy and section of the dentate ligaments.

DISCUSSION

All of the patients with the acute-flexion or tear-drop fracture-dislocation have shown marked instability at the site of the lesion apparently due to changes in the ligaments and in the intervertebral disc. The ligaments torn at the time of dislocation and imperfectly healed by scar tend to stretch and become relaxed. The intervertebral disc is disrupted by the dislocation at the time of injury. The associated fractures of one or more of the adjacent vertebral bodies extend through the vertebral plates. The ensuing hemorrhage, replacement fibrosis and degenerative changes cause thinning of the disc with loss of its resiliency. As pointed out by Luck it is this narrowing and loss of resiliency which stimulate the formation of marginal osteophytes. Repeated episodes of minimal trauma consequent to the abnormal mobility lead to increasing degenerative changes and the formation of larger spurs. Eventually these spurs encroach upon the spinal canal posteriorly leading to pressure on the anterior aspect of the spinal cord.

All five of these cases demonstrate various phases of this problem and indicate the varying degrees of chronic compression of the anterior portion of the cervical spinal cord that may occur.

A quarter of a century ago, A. S. Taylor stressed the importance of recognizing the

chronic compression of the anterior surface of the cord resulting some time after an acute injury to the cervical spine and spinal cord. He stated: "When the cord has escaped entirely, or almost entirely, and has recovered, but the bone deformity has not been corrected and prevented from recurring by proper treatment, after a period varying from a few months to a year, there is likely to develop a transverse pressure myelitis of the segment of cord which rides over the backward-projecting upper margin of the body of the lower vertebra, with corresponding loss of cord function." It is indeed regrettable that this important suggestion in the literature has been overlooked.

In 1947, one of the authors (E. A. K.) [4] called attention to the role played by the dentate ligaments and by the nerve roots, with their surrounding dural sleeves, in anchoring the spinal cord over calcified lesions of the cervical area. This fixation was found to result in chronic compression of the anterior portion of the cervical spinal cord. Patients with such lesions were mistakenly diagnosed as having primary lateral sclerosis. In describing the mechanism involved, it was stated: "In anterior spinal cord compression I believe that, with pressure over a period of time, the pyramidal tracts, because of the greater stress on them and the large size of their fibers, have more disturbance of conductivity than the pain fibers of the spinothalamic tracts, even though the latter are closer to the compressing mass, be it midline herniated nucleus pulposus or tumor. Touch is preserved because, even though the touch fibers of the ventral spinothalamic tracts may fail to conduct, there is still sufficient sensation carried in the more protected posterior columns to prevent the clinical detection of touch disturbance. Postural sense is preserved because the attachments of the dentate ligaments prevent the posterior columns, which are farthest from the compressing mass, from being pressed against the unyielding laminae. Thus may be produced a clinical though not necessarily a pathological picture of lateral sclerosis with pyramidal tract disturbance and little or no sensory change" [4] (Fig. 7). Since this publication, there have been a number of papers published dealing with the problem of the neurological sequelae of cervical spondylosis [1, 2, 3, 5].

In order to prevent the complications associated with calcified lesions lying anterior to the cord which result from recurrent trauma and which cause chronic compression of the anterior portion of the cervical spinal cord, patients with this special acute-flexion tear-drop fracture-dislocation which results in neurological deficit should be treated by traction; surgical exploration by laminectomy should be performed with the patient in traction, and the dentate ligaments should be sectioned. Finally, but extremely important, fusion of the involved portions of the cervical spine in good alignment should be performed. This may be done either at the initial surgical procedure, or, preferably, at a secondary operation. If this type of fracture is present without neurological deficit in the acute phase of the injury, then spine fusion without laminectomy and section of the dentate ligaments is justified.

SUMMARY

The acute-flexion or tear-drop fracture-dislocation associated with injuries of the cervical spinal cord warrants special attention. It is characterized by the separation and downward and forward displacement of the anterior inferior margin of the involved vertebral body. The posterior inferior margin of this same vertebral body is displaced posteriorly into the spinal canal.

Acute injuries of this type may be associated with the syndrome of damage to the anterior aspect of the cervical cord. This syndrome may be due to either destruction of this portion of the cord or to compression by displaced bone or disc material. If due to compression, this may be relieved by a surgical procedure.

In these cases surgical exploration with the patient in traction and section of the dentate ligaments are indicated, if neurological signs are present. Spine fusion should then be performed at the primary operation, or at a secondary procedure. This will prevent

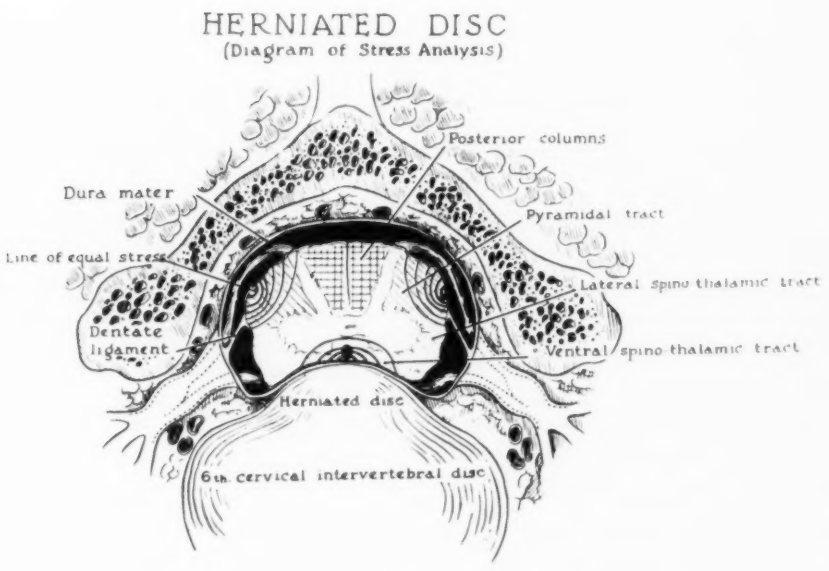

FIG. 7

Diagram showing lines of stress produced by compression of the anterior surface of the spinal cord. Greatest stress is on the anterior tracts, the ventro-spinothalamic tracts, disturbance of which would not be demonstrable by clinical tests. There is slighter stress directly on the pyramidal tracts, while the tracts affecting the hand, being located more centrally, receive the least stress or no stress, which explains why there is frequent sparing of the hands. (Reproduced by permission from the *Journal of Neurosurgery*, **4**: 195, 1947.)

instability of the spine, and the fractured cervical vertebrae will heal in good alignment without the formation of a bony bulge posteriorly. Such bulging may cause chronic compression of the anterior portion of the cervical spinal cord with neurological sequelae. If the tear-drop fracture is present without neurological signs, spine fusion without laminectomy should be performed after spinal re-alignment by cervical traction.

NOTE: The authors wish to express their deep appreciation to Dr. Robert Knighton of the Henry Ford Hospital and Dr. Aage Nielsen of the Harper Hospital, Detroit, Michigan, and to Dr. Thomas Hoen of New York City for their data on some of these patients. They would also like to thank Dr. Carl E. Badgley, Dr. Robert Bailey, and Dr. Hobart Klaaren of the Section of Bone and Joint Surgery of the Department of Surgery, University Hospital, for their aid in the procuring of certain case material.

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Lengths of the Growing Foot*

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The growth of the foot and the age at which it reaches its mature length in the adolescent is often of concern to the orthopaedic surgeon. Particularly is it important to understand the pattern of growth of the foot when surgery which may affect its ultimate length is planned. Since standards for the length of the foot throughout the child's entire growing period have not been available heretofore, the present "norms" have been developed to provide practical values for the expected length of the foot at each age and to relate the growth of the foot itself to that observed in other areas of the body. A detailed study of the growth of the foot has been reported elsewhere.[2]

The measurements of the normal length of the foot which are included in this report were made with a simple wooden caliper, the recorded length being that from the back of the heel to the tip of the great toe when the subject was in a standing position. The children selected had been enrolled in a longitudinal study of growth made over the past fifteen years at the Children's Medical Center. Serial measurements of the normal feet of 227 girls and 285 boys with poliomyelitic conditions in the contralateral foot provided the 3,128 values which were analyzed. In these children, paralysis affected one lower

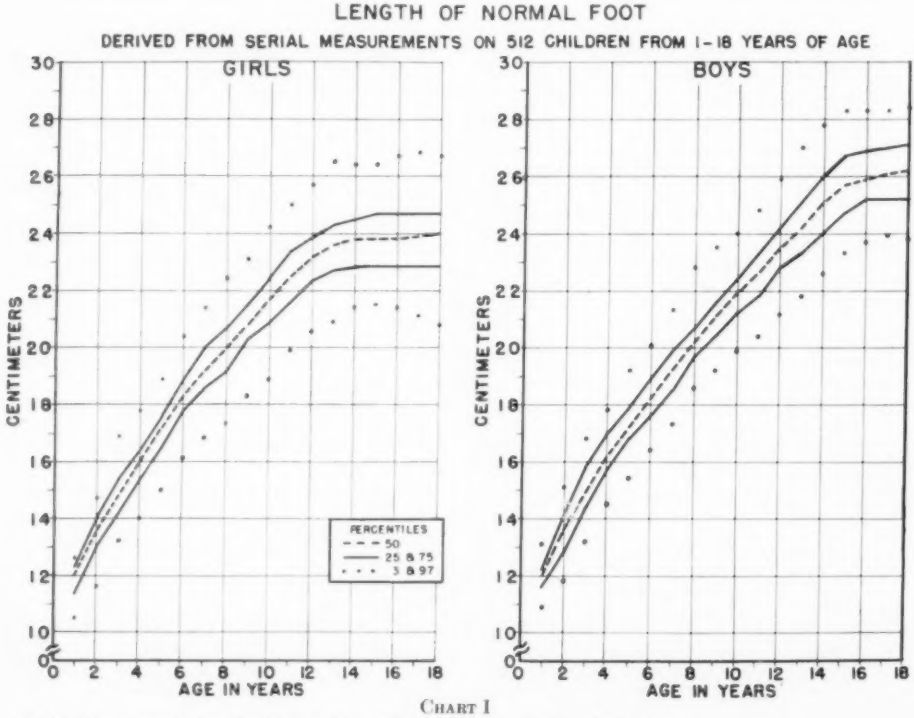

CHART I

* Aided by a grant from the National Foundation for Infantile Paralysis, Inc.

extremity only, all other parts of the body having normal muscle power. The averages derived from this group may reliably be taken as representative of a normal population since no statistically significant difference was found at any age level between this group with poliomyelitis affecting only the opposite member and a small, wholly longitudinal series of normal children.

The distributions which have been evolved from these data provide a standard to which the growth of the individual foot may be referred at all ages from one through eighteen years (Table I and Chart I). Such comparisons with a standard allow one to evaluate the status of a growing foot as well as to assess or to anticipate the potential effects of disease or trauma in this area. The five percentile levels which are presented demonstrate the similarity of the foot among boys and girls at all ages through twelve years

TABLE I

LENGTH OF THE NORMAL FOOT

Caliper Measurements in Centimeters in Weight-Bearing Position Derived from Semilongitudinal Series of 227 Girls and 285 Boys

Girls Percentile						Boys Percentile				
3	25	50	75	97	Age	3	25	50	75	97
10.5	11.4	12.0	12.3	12.6	1	10.9	11.6	12.0	12.2	13.1
11.6	13.0	13.6	14.0	14.7	2	11.8	12.8	13.6	14.1	15.1
13.2	14.3	14.8	15.4	16.9	3	13.2	14.4	14.9	15.8	16.8
14.0	15.4	16.0	16.4	17.8	4	14.5	15.7	16.2	17.0	17.8
15.0	16.5	17.2	17.6	18.9	5	15.4	16.8	17.2	17.9	19.2
16.1	17.8	18.3	18.9	20.4	6	16.4	17.6	18.2	18.9	20.1
16.8	18.6	19.2	20.0	21.4	7	17.3	18.5	19.2	19.9	21.3
17.3	19.2	20.0	20.7	22.4	8	18.6	19.7	20.2	20.7	22.8
18.3	20.3	20.8	21.5	23.1	9	19.2	20.4	21.1	21.6	23.5
18.9	20.9	21.7	22.4	24.2	10	19.9	21.2	21.9	22.4	24.0
19.9	21.6	22.5	23.4	25.0	11	20.4	21.8	22.6	23.3	24.8
20.6	22.3	23.2	23.9	25.7	12	21.2	22.8	23.5	24.2	25.9
20.9	22.7	23.6	24.3	26.5	13	21.8	23.3	24.2	25.1	27.0
21.4	22.8	23.8	24.5	26.4	14	22.6	24.0	25.1	26.0	27.8
21.5	22.8	23.8	24.7	26.4	15	23.3	24.7	25.7	26.7	28.3
21.4	22.8	23.8	24.7	26.7	16	23.7	25.2	25.9	26.9	28.3
21.1	22.8	23.9	24.7	26.8	17	23.9	25.2	26.1	27.0	28.3
20.8	22.8	24.0	24.7	26.7	18	23.8	25.2	26.2	27.1	28.4

and the increasing difference between the lengths of the feet of the sexes after that age. At twelve years of age, the average length of the foot is about the same for girls as for boys, namely 23.2 centimeters as compared to 23.5 centimeters. After this age, the foot in boys continues to grow for four more years during which time the average length of the foot increases 2.7 centimeters. After the age of twelve in girls, however, growth of the foot continues at a slow rate for only two more years with an average total increase in length of only 0.8 centimeter. The average adult length of the foot in boys is thus 2.2 centimeters greater than that in girls.

The feet of both boys and girls grow at a sharply decreasing rate from infancy through the age of five years. Following this, an average annual increase in length of 0.9 centimeter has been observed from five through twelve years of age in girls and from five through fourteen years in boys. An individual child may show a "spurt" in the rate of growth toward the end of this interval but since this may occur at different ages, it does

not notably alter the average figures. After the age of twelve years in girls and of fourteen in boys, growth of the foot proceeds at a markedly decreased rate until an essentially mature length is reached at the average age of fourteen in girls and sixteen in boys.

Completion of linear growth occurs in the foot earlier than in the long bones of the lower extremity. The femur and tibia attain their mature length a year later, at the average age of fifteen in girls and seventeen in boys[1], while total body height increases for an additional two years or so after cessation of growth of the lower extremities.

Consideration of the relative maturity of the individual is important in evaluating the growth of the foot, just as it is in predicting the residual growth in other parts of the body. In the 200 patients in this series who had reached maturity, for example, there was a broad spread in the chronological age at which growth of the foot was completed. Those whose feet continued to grow after the average age for completion of growth were less mature physically and showed retarded skeletal ages. Conversely, those whose feet stopped growing earlier than these average ages showed accelerated maturity. Regardless of the age of final maturation of the individual, precise serial measurements showed that the foot preceded the long bones and total stature both in the age at which the early-adolescent "growth spurt" was seen and in the age at which mature dimension was achieved.

TABLE II

PER CENT OF EIGHTEEN-YEAR SIZE ATTAINED AT SPECIFIC AGES

Longitudinal Series: Ten Boys and Ten Girls

Girls				Boys		
Stature (*Per cent*)	Femur and Tibia (*Per cent*)	Foot (*Per cent*)	Age	Stature (*Per cent*)	Femur and Tibia (*Per cent*)	Foot (*Per cent*)
46.1	34.8	49.9	1	42.6	31.2	45.2
53.2	41.7	57.8	2	49.7	39.2	53.0
63.6	55.1	67.8	4	58.7	49.8	62.0
77.4	73.9	82.1	8	72.4	68.7	75.8
91.3	91.6	97.0	12	84.5	85.4	91.3
99.5	100.0	100.0	16	98.6	99.6	100.0

The foot at all times during the growing period is relatively closer to its adult size than is the total height or the length of the femur and tibia of the same subjects (Table II). Half the mature dimension of the foot, for example, is achieved on the average at one year of age in girls and eighteen months in boys. The femur and tibia, on the other hand, do not attain half their mature length until the ages of three in girls and four in boys. This tendency of the foot to be relatively closer to its adult dimension than other areas measured was found to continue throughout the growing years. Factors which inhibit growth at a particular age, therefore, affect the ultimate length of the foot proportionately less than would similar disturbances in the long bones. If, for example, all the growth centers of the foot were to be destroyed at the skeletal age of twelve years in girls or fourteen in boys, the result would be an average reduction in adult length of only about 3 per cent, amounting to approximately one centimeter. Even if all of these centers were destroyed as early as a skeletal age of ten years in girls or twelve years in boys, one would still expect an average reduction of but 10 per cent or about 2.5 centimeters.

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Fractures of the Tibial Condyle

A Clinical and Experimental Study *

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Conservative as against operative treatment in fractures of the tibial condyles has long been a controversial question [1, 2, 3, 5, 7, 8, 9, 11, 14, 15, 16, 20, 24]. The late effects of this fracture on the knee joint and its subsequent function are generally not well known. Thus, in order to clarify the various aspects of this general problem, experimental and clinical studies have been made. The physiology of the repair in experimentally produced defects of joint surfaces was studied in rhesus monkeys in order to evaluate the gross and microscopic effects of immobilization on the knee joint. A clinical study of 726 fractures of the tibial condyle has been made, with a detailed follow-up study on 227.

EXPERIMENTAL STUDY

The experimental work included the creation of similar defects in the tibial and femoral condyles in both knees of six rhesus monkeys. One knee was permitted

FIG. 1-A

FIG. 1-B

Fig. 1-A: Knee joint of a rhesus monkey with an experimental defect in the patellar groove. The defect had been created two months previously and the knee had been immobilized in a cast. Note the heavy core of adhesions between the defect and the infrapatellar fat pad, as well as the synovial inflammatory changes.

Fig. 1-B: The opposite knee joint with an experimental defect in the patellar groove. The defect had been created two months previously and active use of the knee had been permitted. Note the absence of synovial reaction and pannus and the filling-in of the defect by fibrocartilage.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Los Angeles, California, February 3, 1955. Based on preliminary reports to the Western Orthopedic Association at Coronado, California, October 1952, and at San Francisco, California, October 1954.

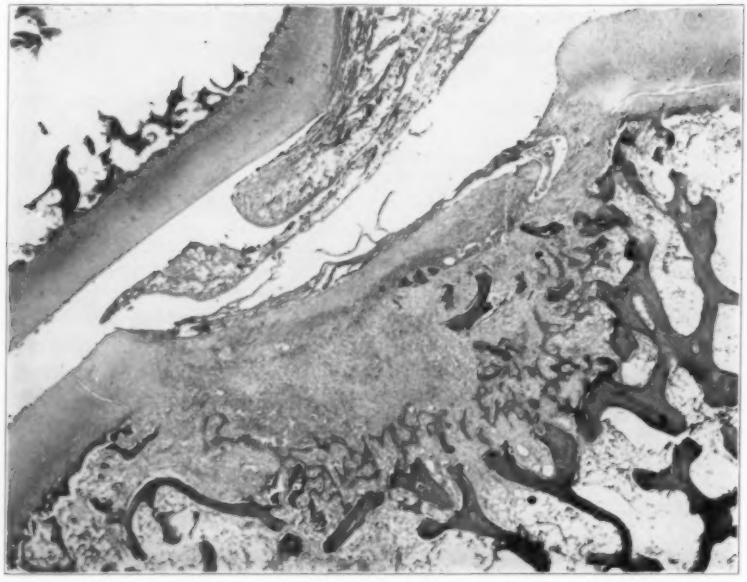

FIG. 2-A

Photomicrograph (× 25) of the immobilized knee after two months showing pannus adherent to the experimental defect with the filling of the defect by fibrous tissue.

FIG. 2-B

Photomicrograph (× 25) of a section from the knee shown in Fig. 1-B after two months of active mobilization. The defect has filled in with vascular fibrous tissue. Note the absence of adhesions over the articular surface.

uninhibited motion from the time of surgery, while the other was immobilized for a period of one to three months in a plaster cast. The animals were sacrificed and the knee joints were subjected to gross and microscopic examination.

It was shown in the experimental animals that immobilization in the presence of defects created in the articular cartilage and articular cortex of the femoral and tibial condyles led to the early formation of a heavy core of adhesions having their origin in the infrapatellar fat pad (Fig. 1-A). When free motion was permitted no adhesions formed in the crater of the defect in either the tibial or the femoral condyle and there was strikingly better progress in the healing process, with less synovial reaction (Fig. 1-B). It was observed in two experimental animals that cortisone given in therapeutic doses for a month had no material influence on the healing response, nor did it appear to alter materially the propensity for adhesion and pannus formation.

The healing of these experimental defects occurred by the ingrowth of fibrous tissue

TABLE I

DISTRIBUTION OF 726 CASES OF TIBIAL CONDYLAR FRACTURE BY SEX, SIDE, AND AGE

Sex	No. of Cases
Male	444
Female	282
Total	726

Side of Fracture	No. of Cases
Right	348
Left	378
Total	726

Age (*Years*)	No. of Cases
0 to 9	3
10 to 19	13
20 to 29	53
30 to 39	103
40 to 49	149
50 to 59	166
60 to 69	145
70 to 79	77
80 to 91	17
Total	726

through the subchondral marrow spaces and, to a lesser extent, from the margins [12]. Vessels and their fibroblastic scaffold were observed to grow in, replacing the area of the defect with granulation tissue which then underwent fibrous condensation. As function was restored, this fibrous tissue was transformed into fibrocartilage which could ultimately differentiate into hyaline cartilage [13, 20] (Figs. 2-A and 2-B). The transformation into hyaline cartilage was generally spotty and could be expected to occur only in those areas subjected to the greatest friction and pressure during joint movement.

CLINICAL MATERIAL

A study was made of all recorded cases of fracture involving the tibial condyles in the Los Angeles County Hospital between July 1940 and December 1952 (679 cases), in the Veteran's Hospital (Wadsworth), West Los Angeles, between 1946 and 1952 (forty cases), and in private practice (seven cases). Avulsion, chip, or sprain fractures were not included. The fractures were treated on large fracture services by orthopaedic surgeons of various schools of training and by orthopaedic residents. General information about the series is recorded in Tables I, II, and III.

CLASSIFICATION

The classification in this series of fractures was determined by the type and extent of disruption of the tibial condyles. The undisplaced fracture was arbitrarily defined as a fracture involving the articular surface but lacking more than three millimeters' displacement as shown by roentgenogram. Measurement of depth of depression was made either

TABLE II

METHOD OF INJURY

Cause of Injury	No. of Cases	Per cent
Auto injuries to pedestrians	411	57
Auto injuries to auto occupants	74	10
Fall, twist, or both	191	26
Other	16	2
Unknown	34	5
Total	726	100

TABLE III

ASSOCIATED INJURIES

		No. of Cases	Per cent
No associated injury		450	62
Injury to other arm or leg		113	15
Fracture in same leg		195	27
Subcondylar (tibia)	104		
Femoral condyle or patella	20		
Other	71		
Fractured fibular head		281	39
Fractured condyle and fractured tibial spines		82	11

from the remaining intact articular surface or from a line drawn as an extension of the other tibial condyle to the point of maximum depression. The displaced fractures were divided into (1) the local-depression type, with comminution of the articular surface (Figs. 3-A and 3-B), (2) the total-depression type with depression of the entire intact articulating surface of the condyle (Fig. 3-C), and (3) the split type, in which lateral displacement without depression was the presenting feature (Fig. 3-D) (Table IV). Fracture of the medial tibial condyle was observed in eighty-nine cases (12 per cent of the series).

OPEN REDUCTIONS

There were forty-four open reductions in the series (Table V). A delay of one to thirty days, with an average delay of eight days, was observed prior to surgery. The surgery

TABLE IV

CLASSIFICATION OF 726 FRACTURES OF THE TIBIAL CONDYLE WITH DIVISION INTO TYPES OF TREATMENT USED

Method of Treatment	Undisplaced	Local Depression	Total Depression	Split	Total	Per cent
Cast	158	262	95	24	539	74.2
Traction	11	22	15	6	54	7.4
Open reduction	0	29	8	7	44	6.1
Closed reduction	4	20	20	10	54	7.4
Miscellaneous or unknown	8	18	4	5	35	4.9
Total	181	351	142	52	726	100.0
Per Cent	24.9	48.3	19.6	7.2		100.0

TABLE V

ANALYSIS OF FORTY-FOUR OPEN REDUCTIONS IN 726 PATIENTS

Type of Fracture	No. of Cases	Average Fracture Displacement (*Millimeters*)	State of Meniscus	Internal Fixation	Bone Graft	Average Period of Immobilization (*Months*)
Local depression	29	14.2*	Torn (18) Intact (3) Unknown (8)	Screw (10) Bolt (3) Other (4) None (12)	Cancellous (11) Cortical (5) None (12) Fibular head (1)	2.7**
Total depression	8	12.6	Torn (2) Intact (1) Unknown (5)	Screw (2) Bolt (3) None (3)	Cancellous (3) None (5)	3.0
Split fracture	7	12	Torn (4) Intact (0) Unknown (3)	Screw (4) Bolt (2) None (1)	None (7)	2.3

* The greatest amount of displacement was twenty-seven millimeters and the least, eight.
** The longest period of immobilization in this group was eight months.

consisted in an exposure of the knee joint and of the upper end of the tibia on the affected side, with excision of the meniscus in thirty cases; in some cases, excision was done to gain a better visualization of the fracture. The depressed articular surface was restored under direct vision by prying up the depressed fragments with an osteotome from below. Internal fixation by screws or bolts was common and was frequently supplemented by cancellous or cortical bone grafts. Anatomic reduction was not commonly observed by roentgenogram in the open reductions, and in several cases marked redisplacement occurred after operation. The loss of reduction was noted either when no grafts had been used or when cancellous chips had been used sparingly. Technical surgical errors, such as incomplete reduction, inadequate bone-grafting, and inadequate internal fixation, were noted in over half of the cases and directly affected the outcome.

THE FOLLOW-UP SERIES

The follow-up examination was by personal interview in 227 cases two to thirteen years after the fracture, with an average follow-up period of five years; 85 per cent of the cases were seen by the authors (Table VI). Consideration of subjective complaints, comparative examination of both knees, and roentgenographic examination were included in the follow-up interview.

FIG. 3-A FIG. 3-B FIG. 3-C FIG. 3-D

Figs. 3-A and 3-B: Drawings illustrating local-depression fractures.
Fig. 3-C: Total-depression fracture. Fig. 3-D: Split fracture.

TABLE VI

Cases	No. of Cases	Per cent of Series
Personally followed	193	26.6
Followed by other orthopaedists	34	4.7
Died	94	12.9
Refused follow-up examination	124	17.0
Lost to follow-up	281	38.8
Total	726	100.0

METHOD OF GRADING RESULTS

The results were judged independently by anatomic and functional grading and were graded as *excellent*, *good*, *fair*, or *poor* (Table VII). Reduction of the fracture, development of degenerative joint changes, and cosmetic appearance were considered in the anatomical grade. In determining the functional grade, the degree of motion, extension of the knee, abnormal mobility, strength, and pain were included. For convenience in the analysis the excellent and good results were combined into the acceptable group, and the fair and poor into the non-acceptable group. An acceptable anatomic result required reduction of the fracture within three millimeters, no more than 5 degrees' increase in valgus or varus deformity, and minimal or no degenerative joint change. An acceptable functional result required at least 90 degrees of knee motion, with good endurance and strength. Mild intermittent aching, slight increased lateral mobility, and loss of the last

TABLE VII

CRITERIA OF GRADING USED IN THE FOLLOW-UP STUDY OF 227 TIBIAL CONDYLAR FRACTURES

Anatomic Grade	
Excellent (All of the following)	*Good* (Not more than one of the following)
1. Normal valgus within 5 degrees	1. Valgus of more than 5 degrees
2. Restoration of displacement within 3 millimeters	2. Minimal degenerative joint changes
3. No degenerative joint changes	
Fair (Not more than two of the following)	*Poor* (All of the following)
1. Valgus deformity of more than 10 degrees	1. Moderate or severe degenerative joint changes
2. Moderate degenerative joint changes	2. Lack of fracture reduction
3. Lack of fracture reduction	3. Valgus deformity of more than 10 degrees
Functional Grade	
Excellent (All of the following)	*Good* (Not more than one of the following)
1. Full extension of the knee	1. Lack of knee extension beyond 170 degrees
2. 120 degrees range of motion or more	2. Excessive lateral mobility
3. No abnormal abduction rocking	3. Mild aching each day
4. Normal strength and endurance	4. 90 degrees total range of motion
5. Occasional ache permissible	5. Weakness or easy fatigue
Fair (Not more than two of the following)	*Poor* (Three or more of the following)
1. Lack of knee extension more than 170 degrees	1. Lack of useful motion (less than 75 degrees)
2. 75 degrees range of motion	2. Unable to work
3. Discomfort for ordinary activity	3. Pain in all activity
4. Excessive lateral mobility	4. Excessive lateral mobility

FIG. 4-A

FIG. 4-B

Fig. 4-A: Case 1. P.L. Anteroposterior roentgenogram of an undisplaced lateral tibial condylar fracture. Note the presence of a subcondylar fracture. A long leg cast was used for three months.

Fig. 4-B: Roentgenogram made thirty months later. An excellent anatomic and functional result was obtained.

few degrees of extension were permitted. Patients with an unacceptable anatomic result lacked reduction of the fracture or showed cosmetically apparent valgus or varus deformity with degenerative joint changes. Patients with unacceptable functional results lacked 90 degrees of knee motion, had lateral instability, and experienced pain in ordinary daily activities.

ANALYSIS BY FRACTURE TYPE

Undisplaced Fractures

The fractures in this group were treated predominantly by cast immobilization for an average of three months, full weight-bearing being resumed in an average of four months (Figs. 4-A and 4-B). Twenty-nine patients were followed two or more years (Table VIII). In no case was a fracture transformed from an undisplaced to a displaced type by the lack of immobilization, too early exercise, or premature ambulation. The range of motion was well recovered in most cases. It was noted that when the time in the cast was short the knee motion recovered rapidly, and when the time in the case was excessive the functional recovery was delayed. The patients treated without a cast recovered motion and were weight-bearing considerably earlier than those in the immobilized group. Symptomatic instability of the medial collateral ligament persisted in several cases.

Local Depression

There were 132 cases of comminution and depression of the articular surface of the tibial condyle seen at follow-up examination (Table IX) (Figs. 3-A and 3-B). The depth of depression averaged nine millimeters (harmonic mean 7.9 millimeters) with a maximum of twenty-eight millimeters. In 37 per cent of the cases there were depressions of one centimeter or more; these provided the real challenge in selection of treatment. Because of other fractures in the extremity four patients were treated entirely in traction.

The anatomic results in cases without open reduction were poor, as this fracture

TABLE VIII

RESULTS IN UNDISPLACED FRACTURES

Method of Treatment	No. of Cases	Acceptable Anatomic Results		Acceptable Functional Results	
		(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
Immobilization for less than one month	9	9	100	9	100
Immobilization for more than one month	20	18	90	18	90
Total	29	27	93	27	93

TABLE IX

RESULTS IN LOCAL DEPRESSION FRACTURES TREATED BY VARIOUS METHODS

Method of Treatment	No. of Cases	Acceptable Anatomic Results		Acceptable Functional Results	
		(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
No cast or cast for less than 4 weeks	23	0	0	20	87
Cast immobilization over 4 weeks	76	1	1.3	57	75
Manipulation followed by cast	2	0	0	1	50
Traction	4	0	0	3	75
Open reduction	20	7	35	11	55
Miscellaneous	7	0	0	0	0
Total	132	8	6.0	92	70

obviously cannot be reduced without surgery [6, 9, 12]. Residual valgus or varus deformities were noted in over 40 per cent of this group (Table X). It is noteworthy that the time in the cast was not significantly * different in the cases in which valgus deformity developed from the time in cases in which it did not develop, indicating that prolonged immobilization failed to decrease the incidence of permanent angular deformity. There was a significant correlation between the depth of depression and the degree of valgus; however, factors other than the depth of depression must play some part ** (Chart I). Valgus deformity was noted in cases with depressions of less than one centimeter but with less frequency and severity than was observed in cases with greater degrees of depression. Improvement in the anatomical grade was manifest in the open reductions by fracture reduction and by somewhat less frequent and less severe residual valgus deformities (Table X).

The functional results in the cases without operation were considerably better than were the anatomic results (Table IX). The depth of the depression was related directly to the functional result. The harmonic means of the degree of depression in the cases with acceptable and those with non-acceptable results differed significantly. In the twenty cases with operation the harmonic mean in those with acceptable results was 10.5 millimeters, while in those with unacceptable results it was 15.4 millimeters.

The duration of immobilization did not appear to influence the stability of the knee. However, when immobilization was prolonged, it appeared to affect both the time required for recovery of motion and the degree of eventual recovery. Analysis of comparable cases in which treatment was by closed methods or by open reduction did not show significantly

* The term "significant" indicates a probability of .05 or less.

** The r value (coefficient of correlation) was not great, indicating that this is not the only factor. Cartilage thinning on the affected side of the joint is one possible factor.

TABLE X

VALGUS OR VARUS DEFORMITY IN LOCAL DEPRESSION FRACTURES TREATED CONSERVATIVELY AND TREATED BY OPEN REDUCTION

Type of Treatment	No. of Cases	Acceptable Anatomic Results		Valgus or Varus Deformity		Acceptable Functional Results	
		(No. of Cases)	*(Per cent)*	*(No. of Cases)*	*(Per cent)*	*(No. of Cases)*	*(Per cent)*
Conservative							
Less than 1 cm. displacement	79	1	0	27	35	61	77
More than 1 cm. displacement	33	0	0	19	58	20	61
Open reduction	20	7	35	10	50	11	55

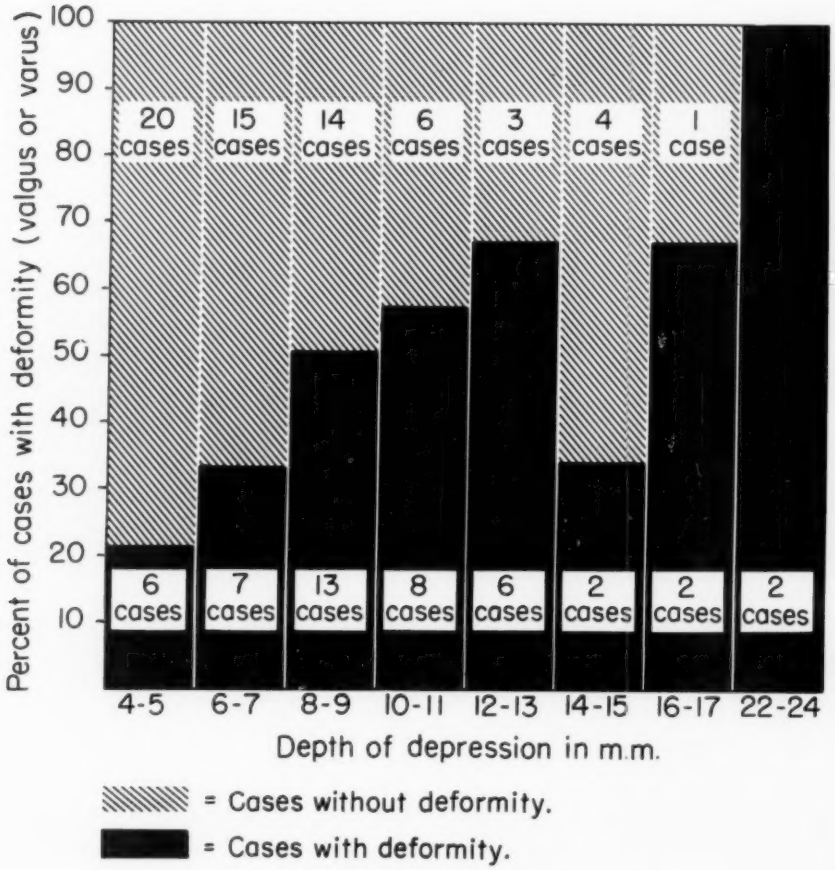

CHART I

This chart is based upon the follow-up study of 112 conservatively treated local-depression fractures of which forty-six showed valgus or varus deformity. The cases were divided into eight groups according to depth of depression measured in millimeters. The percentages of each group with deformity (valgus or varus) are shown. Note that the degree of deformity was less severe when the depression was less than one centimeter.

different functional results. However, it should be understood that prolonged cast immobilization was commonly used in this series. Open reduction improved the anatomic result but did not improve the functional result. In the analysis of the poor results excessive lateral mobility and restricted range of motion were observed most frequently. Aching discomfort was common but disabling pain was rarely encountered.

Total Depression

The fracture of the total-depression type was usually an impacted fracture not uncommonly involving the medial condyle with downward and outward displacement (Fig. 3-C). Forty-seven cases were followed in this group (Table XI). Valgus or varus deformity was frequently apparent from the moment of injury and when reduction was not obtained the deformity usually remained permanent. The harmonic-mean depression was 5.8 millimeters, but 16 per cent of the fractures were depressed more than one centimeter. Most cases were treated by cast immobilization for an average of three months, although in several cases manipulation under anaesthesia was done. Manipulative reduction under anaesthesia, although not useful in the group with local depression, permitted reduction in some of the fractures with total depression. The reduction, however, was often lost in plaster-cast immobilization.

The anatomic results were similar to those in the local-depression group since the surgeon usually accepted the impacted position of the fracture without correction of the valgus or varus deformity. The valgus or varus deformity was related to the degree of displacement * and was not significantly influenced by the period of immobilization.

* Their value was not great, indicating that other factors play an important part.

FIG. 5-A

FIG. 5-B

Fig. 5-A: Case 2. R.A. Initial roentgenogram, showing a typical central condylar depression of one centimeter. The patient was treated in "bow-leg" cast for three months and used crutches for one year.

Fig. 5-B: Follow-up roentgenogram after three years, showing valgus deformity, with the lateral femoral condyle "dipping" into the tibial defect. Roentgenographic evidence of filling-in of the defect by bone is lacking. The anatomic result was poor. The functional result was good, with a full range of motion, but with abduction "rocking" of 10 degrees.

FIG. 6-A

FIG. 6-B

Fig. 6-A: Case 6. T.B. Roentgenogram of a markedly depressed fracture of the lateral tibial condyle.

Fig. 6-B: Roentgenogram made four months after surgical elevation of the depressed fragment. The reduction was held by a screw and cancellous chips. However, aseptic necrosis probably occurred, with crumbling of the major fragment.

Fig. 6-C: Six years after the fracture the roentgenogram showed valgus deformity, incongruity, and evidence of a bony defect. The anatomic result was poor. The functional result was fair; the range of motion was from 70 to 175 degrees, with 10 degrees of lateral instability.

FIG. 6-C

The functional results were acceptable in 79 per cent of these cases. Instability and lack of complete knee extension were commonly seen in the unacceptable cases.

Split Fractures

The split fracture exhibits lateral displacement of a condylar fragment without depression. This type of fracture should be differentiated from the common local-depression fracture with a split fragment and a depression within the condyle (Fig. 7-A). Displacement of the split fractures averaged eight millimeters, with displacement of one centimeter or more in 35 per cent of cases. Cast immobilization without an attempt at reduction was used frequently. Manipulation under anaesthesia, with use of the Böhler clamp or a similar device, was also used, often improving the position of the fracture. In cases without operation bony union usually required three or more months of cast immobilization with resultant loss of motion. Open reduction with internal fixation was used in markedly displaced fractures allowing early motion.

Nineteen cases were available in the follow-up series. Valgus or varus deformities were not noted. Numerically insufficient cases preclude statistical analysis (Table XII).

GENERAL OBSERVATIONS

Effect of associated injuries: Immobilization of the knee was required for longer periods and the time necessary for recovery of function was prolonged. Association of tibial-spine fractures did not materially influence the functional result.

Effect of cast time on the functional result: In conservatively treated cases with unacceptable functional results the cast time was significantly longer than in the cases with acceptable results.

Age related to functional result: No significant difference was noted in the functional prognosis among the different age groups [5].

TABLE XI

RESULTS IN TOTAL DEPRESSION FRACTURES TREATED BY VARIOUS METHODS

Treatment	No. of Cases	Acceptable Anatomic Results	Acceptable Functional Results	
			(No. of Cases)	*(Per cent)*
Immobilization for less than one month	9	0	9	100
Immobilization over one month	27	0	19	70
Manipulation	6	0	5	83
Traction	1	0	1	100
Open reduction	3	1	1	33
Miscellaneous	1	0	0	
Total	47	1	35	74

FIG. 7-A

FIG. 7-B

Fig 7-A: Case 7. F.E. Roentgenogram of a local-depression fracture (note depressed articular cortex) with a condylar fragment displaced outward. This was treated by open reduction, with elevation of the depressed cortex and internal fixation of the lateral fragment to the main portion of the upper end of the tibia. Cast immobilization was used for thirteen weeks.

Fig. 7-B: Roentgenogram made six years after the fracture, showing irregularity and narrowing of the lateral cartilage space. The patient gave a history of intermittent locking accompanied by pain. Arthrotomy revealed marked pannus covering most of the lateral compartment. Joint débridement was carried out, with relief of locking. The anatomic result was good and the functional result was fair.

Relation of valgus deformity to development of degenerative joint change: The frequency of degenerative joint change was significantly greater in patients with residual valgus deformity [11, 14].

DISCUSSION

No attempt has been made to present a review of the extensive and controversial literature pertaining to this subject. However, certain key references have been cited to point out areas of differing opinion.

It has been noted, both clinically and experimentally, that protracted immobilization is likely to create a destructive degree of fibroplasia which can permanently limit joint mobility by the creation of heavy adhesions and pannus formations. Early mobilization tends to destroy the pannus formations and to prevent maturation of adhesions to the point where they might permanently limit joint motion. Injuries of the type represented

TABLE XII

RESULTS IN SPLIT FRACTURES TREATED BY VARIOUS METHODS

Method of Treatment	No. of Cases	Acceptable Anatomic Results		Acceptable Functional Results	
		(No. of Cases)	*(Per cent)*	*(No. of Cases)*	*(Per cent)*
Cast immobilization	10	0	0	4	40
Traction-manipulation	4	2	50	2	50
Open reduction	5	3	60	3	60
Total	19	5	26	9	47

FIG. 8-A

FIG. 8-B

Fig. 8-A: Case 8. M.K. Roentgenogram showing a total-depression fracture. Note the absence of damage to the articular cortex. The fracture was treated by manipulation, followed by immobilization in a cast for five weeks.

Fig. 8-B: Roentgenogram made six years later at follow-up examination, showing failure of reduction with evident valgus deformity. The range of motion was from 50 to 180 degrees. Except for some instability the functional result was good. The anatomic result was poor.

FIG. 9-A

FIG. 9-B

FIG. 9-C

Fig. 9-A: Case 12. C.S. Roentgenogram showing a split fracture which was treated by open reduction.

Fig. 9-B: Postoperative roentgenogram showing internal fixation. There appears to be excessive impaction of the condyles.

Fig. 9-C: Roentgenogram made two and one-half years later showing an excellent anatomic result. The functional result was good, with a range of motion from 100 to 180 degrees.

by fractures of the tibial condyle may cause two varieties of joint reaction. The one response, a fibroplasia, under proper circumstances is a useful and healing response, but under the circumstances of too complete and too prolonged immobilization it can be a destructive fibroplasia and can lead to permanent joint damage with impairment of function, in particular to permanent loss of motion. This response, referred to by one of the authors [18, 19] as a traumatic arthrofibrosis, is a destructive fibrosis. The other response is one of degeneration of the articular cartilage; this is a long-range process taking place in articular cartilage which has been damaged but in which function is preserved. This would be traumatic degenerative joint disease, or traumatic osteo-arthritis. The term "end result" has not been applied in this study since it is likely that throughout the life of the patient one or several of the changes described will appear as a direct or indirect result of the fracture.

The clinical study provides further information relative to the long-term results from many forms of current treatment. Some reflection on the controversial issues is indicated in the light of this information. Anatomic reduction has long been advocated as necessary for the complete restoration of joint function. The follow-up study on unreduced fractures reveals a remarkable recovery of painless motion despite the lack of reduction demonstrated by roentgenograms. The penalty, however, of this treatment has been the per-

sistence of a cosmetically undesirable valgus or varus deformity. Open reductions, on the other hand, have been condemned by many as assuring poor functional results. These were well illustrated in this series by the cases in which technical errors had occurred. The remaining cases in which open reduction was done showed at least as much recovery of function as comparable cases treated by conservative means. Improvements in surgical technique, especially in the use of bone grafts and internal fixation, will undoubtedly allow much better functional results by eliminating prolonged postoperative immobilization. The decision between conservative treatment or open reduction can only be made intelligently when all of the known factors are carefully assessed.

The following suggestions for treatment are outlined by the authors. The active exercises should begin not later than three to four weeks after fracture and should include quadriceps-building non-weight-bearing exercises. Weight-bearing should not be permitted until 90 degrees of knee motion and roentgenographic evidence of union are present.

Undisplaced fractures: Immobilization by a splint or cast is recommended during the painful two to three weeks after the fracture. Active exercises are then started but weight-bearing is delayed until bony union is present.

Local-depression fractures: In fractures displaced less than one centimeter, non-operative management is recommended, with use of a cast or traction during the period of early inflammatory reaction. Quadriceps-conditioning exercises while the extremity is still in the cast are helpful. After three to four weeks active movements should be started as previously outlined. Weight-bearing is delayed until bony union is present. Open reduction should be considered in depressions of one centimeter or more. The reduction should be mechanically sound with sufficient internal metallic or bone-graft support, or both, to permit the cast to be removed at three to four weeks for active exercise. Support by a cortical-bone graft beneath the elevated condyle should be considered [17,21]. The elderly patient with a local-depression fracture and displacement of more than one centimeter may be treated non-operatively; valgus or varus deformity will probably result but function will be adequate.

Total-depression fractures: Fractures with minimal displacement are best treated by cast and later mobilization. Fractures with displacement of more than eight millimeters can often be reduced under anaesthesia by manipulation and traction. The reduction is difficult to hold in a cast but will usually be retained in continued traction. Difficult fractures may be reduced under anaesthesia on the fracture table, with strong sustained skeletal traction of sixty to seventy pounds and manual molding of the fragments until reduction is secured (Figs. 10-A to 10-D). Traction of fifteen pounds is maintained during the initial three-week period; thereafter, gradual decrease in traction weight permits the patient active motions of the knee. At four weeks 90 degrees of motion should be present and by six weeks the traction may be completely removed for non-weight-bearing exercises. With an adequate reduction valgus or varus deformity should be uncommon. Open reduction should be reserved for cases with displacement of one centimeter or more in which closed manipulation has been unsuccessful.

Split fractures: Open reduction with simple, secure internal fixation permitting early joint mobility will give the best results when the displacement is more than one-half centimeter. The milder cases are treated essentially as undisplaced fractures.

SUMMARY

Seven hundred and twenty-six tibial condylar fractures have been analyzed, with follow-up studies from two to thirteen years in 227 cases.

Conservative treatment is indicated in undisplaced fractures, local-depression fractures with displacement of less than one centimeter, and split fractures with displacement of less than one-half centimeter. Manipulation under anaesthesia with traction is indicated in total-depression fractures and in split fractures with shattering of the upper tibial

FIG. 10-A

FIG. 10-B

Fig. 10-A: Case 13. J.D. Initial roentgenogram of a split fracture, showing marked distortion of the knee joint.

Fig. 10-B: Roentgenogram showing the effect of sixty-eight pounds of skeletal traction (the patient was under spinal anaesthesia).

FIG. 10-C

FIG. 10-D

Fig. 10-C: Roentgenogram made with the limb in sixty-eight pounds of traction after the application of manual compressive force supplemented by the judicious use of an impacting mallet. The extremity was held in twenty pounds of traction for two weeks. Thereafter, traction was reduced to ten pounds and active knee motion was encouraged.

Fig. 10-D: Roentgenogram made three years after the fracture. Both the anatomic and the functional results were excellent. The range of motion was from 55 to 180 degrees.

surface. Open reduction is indicated in local-depression fractures displaced more than one centimeter, total-depression fractures irreducible under anaesthesia, and split fractures with displacement of more than one-half centimeter.

It is the opinion of the authors, based upon this clinical and experimental study, that early active motion is most important in obtaining optimum results in fractures of the tibial condyle.

NOTE: The authors wish to express their gratitude to Frederick J. Moore, M.D., of the Department of Experimental Medicine, University of Southern California School of Medicine, for valued assistance and counsel in the statistical analysis of the data presented.

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DISCUSSION

DR. SYLVESTER J. O'CONNOR, ANN ARBOR, MICHIGAN: I find that discussion will be difficult, because I am in nearly complete agreement with everything that has been said.

We have been for a number of years treating severe compression fractures of the tibial plateau with

heavy traction. Our principle has been the use of early active exercise to bring the plateaus into their proper alignment and reduce the dislocation that may be present. We believe that, through the molding process described by Dr. Hohl, good union will occur and good to excellent functional results will be obtained. It has been our impression that early active exercises prevent interarticular adhesions, since motion by the femoral condyles helps to mold the tibial plateau.

A number of surgeons have been of the opinion that arthrotomy should be done in all fractures of this type in order to replace the bone fragments and to excise the torn menisci. We have not had the opportunity to open any of these knees after they have been treated in this manner, because the functional results have been satisfactory. We did do some pneumo-arthrographic studies, and found that not infrequently a portion of the menisci is depressed into the lateral compartment of the plateau. Despite the fact that there has been displacement of the cartilages, such patients have not had symptoms severe enough to warrant an arthrotomy.

The authors have mentioned the possibility of valgus or varus deformity resulting from these fractures. It is our opinion that if immobilization in a long double upright caliper is used for a period of approximately six months after injury, this deformity can be avoided. The reason for this is that the bone in the proximal portion of the tibia is cancellous and extremely soft, and consequently needs to be protected from weight-bearing. It is also important to build up the quadriceps on the affected side to the point where it is as strong as that on the unaffected side or even stronger, in order to give support and stability to the knee joint. If good quadriceps support is not present, these patients will have symptoms of weakness in the knee; this may well cause a secondary disability aggravating the primary injury.

From our clinical experience we would agree with the authors that early active mobilization is mandatory in treatment of fractures of the tibial plateau, even if the fracture is treated by open reduction in order that interarticular adhesions do not occur.

Dr. Robert Lee Patterson, Jr., New York, N. Y.: I have been interested in fractures of the tibial plateau since 1942. During the War, if these injuries were of the undisplaced type, they were kept in plaster for at least six weeks, often much longer. If the injury was of the split type, or the totally depressed type, either open reduction and fixation was not allowed in the theater, or the surgeons were not experienced enough to do the job correctly. In both cases the patients had to be returned home for definitive care.

With these discouraging conditions, we tried the opposite approach. The hemarthrosis was aspirated and a closed reduction was carried out with aid of a mallet and a Böhler clamp. After this skin traction was applied to the tibia and the extremity was placed in a Thomas splint and a Pearson attachment. Passive motion was begun the next day. Between the third and fourth day these patients had full extension and 90 degrees of flexion actively. No weight-bearing, of course, was allowed before twelve weeks; by that time healing was good and function was excellent.

Until I received the authors' paper, I did not realize why this method was so satisfactory. In their experimental work, they have shown that early motion, by producing friction and pressure, will tend to decrease the formation of adhesions, increase healing at the fracture site, and even make possible the growth of hyaline cartilage rather than fibrocartilage. Thus the authors have shown experimentally, as we found out clinically, that the essential factor in treating fractures in the knee joint is early motion.

The authors' clinical studies reveal that although anatomical appearance was for the most part unsatisfactory, function was excellent in a high percentage of the cases. This has been our experience also, and we agree that in the average type of fracture, closed reduction should be performed, followed by early mobilization. In a severe, totally depressed and split type of fracture, regardless of the amount of displacement, the same treatment should be carried out. If this proves unsatisfactory, open reduction should be performed. We agree with the authors that the paramount consideration is fixation of the fragments so that very early motion can be started.

Dr. Luck (closing): It might be in order to make a comment or two on the reactions of joints to trauma as observed in our experimental and clinical studies.

It has been repeatedly emphasized that immobilization is not an innocuous procedure. There is wide individual variation, some patients tolerating it poorly, some well. We must come to the conclusion that the joint is so constructed, its physiological processes so ordered, that healing proceeds best when a certain amount of function—not weight-bearing, but muscle activity and motion—can be carried out. The importance of immobilization in the healing process following trauma has probably been overestimated in the past, and the tremendous capacity of the joint to heal under limited programs of motion has been underestimated. It has been pointed out that the functional results were better than the anatomic results in cases without operation. However, with a valgus or varus deformity which would persist in such cases, degenerative changes as a result of the impaired mechanics of the knee would take place earlier than they would if the mechanics were better restored. However, we cannot recommend routine operative management.

The experimental correlation in these cases has been exceedingly interesting. The reaction of joints, particularly the fibroplasia that can occur following severe trauma, such as when fractures occur in or near joints, suggested to me the term "traumatic arthrofibrosis". The fact that this fibroplasia can be destructive and can go far beyond a healing response deserves emphasis again and again.

Providing Automatic Grasp by Flexor Tenodesis *

BY JAMES N. WILSON, M.D., LOS ANGELES, CALIFORNIA

Fusion of the wrist has been a commonly accepted orthopaedic procedure for many years. The principle of stabilization of the joint to overcome pain is not subject to criticism in most cases. In paralytic upper extremities, however, wrist stabilization should be subjected to close scrutiny. The primary aim of this paper is to familiarize the reader with a method of treating paralytic hands which relies upon the preservation of wrist mobility for its effectiveness. By this method some degree of function can frequently be restored.

An automatic mechanism which provides the basic functions of grasp and pinch can be obtained if the patient possesses voluntary dorsiflexion of the wrist. The functioning of this automatic mechanism can be observed in the normal hand (Fig. 1). When the wrist is allowed to be palmar flexed by gravity, the fingers and thumb extend and the hand opens. When the wrist is dorsiflexed, the fingers flex to form a weak grasp and the thumb approximates the side of the index finger to provide pinch. The motions observed can occur in the complete absence of any voluntary activation of the digits and are dependent upon the checkreining effect of the long flexor and extensor tendons which cross the wrist joint.

FIG. 1

A double exposure of a normal hand showing the automatic activation of the digits produced by motions of the wrist. Dorsiflexion of the wrist causes the digits to assume the grasping and pinching position. Palmar flexion causes them to extend.

The strength of automatic pinch and grasp is dependent upon the tightness of the flexor tendons and the power of dorsiflexion of the wrist. A surgically produced checkrein effect can be obtained by tenodesis of the long flexor tendons of the fingers and thumb to the lower portion of the radius (Figs. 2 and 3). Opposition of the thumb is secured through tenodesis of the proximal end of an opponens transfer to the lower end of the ulna. The purely automatic motions thus provided are rather crude in nature and many of the finer functions of the hand are not possible. It may be advisable, therefore, in those cases in which further motor power is available, to perform additional tendon transfers to gain a measure of voluntary activity.

Bunnell has utilized these principles in patients with quadriplegia who have retained a good radial wrist extensor and a good brachioradialis. In his procedure the brachioradialis is sutured to the flexor tendons distal to the point of tenodesis, with the result that a final voluntary clench is added to the grasping function. Hendry has performed tenodeses in paralyzed hands even in the absence of any voluntary wrist activity, relying on forearm rotation plus gravity to provide wrist motion. Thus when the forearm is supinated, the wrist dorsiflexes and the fixed tendons cause the fingers to flex. The power of grasp is

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Los Angeles, California, January 28, 1955. Revision received for publication May 21, 1956.

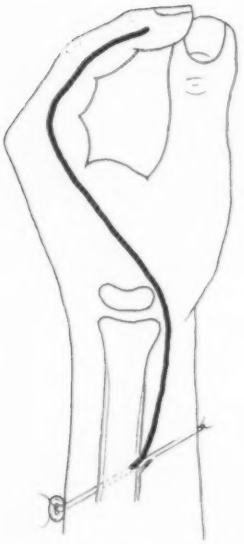

FIG. 2

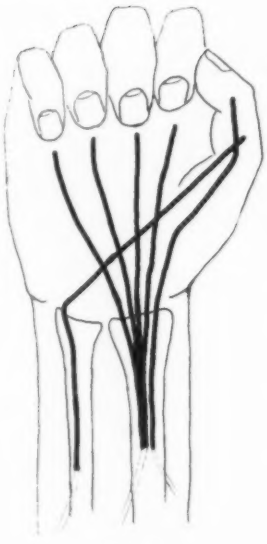

FIG. 3

Fig. 2: In the tenodesis operation, the digital flexor tendons are sectioned at their musculotendinous junction in the forearm and are inserted beneath a volar cortical bone flap. Fixation is secured by means of pull-out wires. If the patient's needs make a thumb-to-index-finger apposition desirable, the index-finger tendon should be made less tight than the other tendons.

Fig. 3: This line drawing demonstrates fixation of the tendons of the flexor pollicis longus and flexor digitorum profundus to the radius and fixation of the opponens transfer to the ulna. The opponens tenodesis is performed by Bunnell's technique, the tendon being passed subcutaneously across the palm and a pulley effect provided at the pisiform bone. If the extensor pollicis brevis tendon is too short, a tendon graft may be used, the distal end being sutured into the tendinous insertion of the abductor pollicis brevis.

dependent upon the weight of the hand and the additional weight of any article placed in the hand.

This paper is based upon a series of four cases in which some degree of function was restored to an otherwise useless extremity by procedures utilizing the principles of automatic digital motion. In two of our cases, spastic hemiplegia had developed following a cerebrovascular injury. One patient had residual paresis as a result of poliomyelitis, and one patient had quadriplegia as a result of an injury to the cervical spine.

CASE REPORTS

CASE 1. M. L., a male, twenty-six years old, had spastic hemiplegia of the left side as a result of the rupture of an intracranial aneurysm when he was ten years of age. In the left arm there was fairly good control of the muscles about the elbow, including the brachioradialis. However, everything below the elbow was spastically rigid, resulting in clenching of the fist and a fixed flexion contracture of the wrist. Surgery was carried out on January 18, 1952, at which time all the wrist flexor tendons and all the long flexor tendons of the fingers and thumb were severed, thus allowing the wrist to be passively dorsiflexed. The brachioradialis was then detached at its insertion and sutured to the tendon of the extensor carpi radialis brevis. The flexor pollicis longus and all the tendons of the flexor digitorum profundus were then fixed to the radius. In order to provide opposition, the tendon of the extensor pollicis brevis was rerouted across the palm and fixed to the ulna.

FIG. 4-A

FIG. 4-B

Figs. 4-A and 4-B: Case 1. Photographs made two and one-half years after surgery.
Fig. 4-A: Note the amplitude of wrist dorsiflexion possible as a result of the brachioradialis transfer.
Fig. 4-B: This photograph demonstrates the involuntary activation of the spastic flexor pollicis brevis and adductor pollicis which occurs when the wrist is dorsiflexed.

FIG. 5-A

FIG. 5-B

Fig. 5-A: Case 3. This photograph shows the position of the fingers upon maximum dorsiflexion of the wrist.

Fig. 5-B: The thumb could be pulled into the abducted position as a result of the opponens tenodesis. Voluntary flexion of the terminal joint of the thumb was made possible by the brachioradialis transfer.

Fig. 5-C: This photograph demonstrates the method used by the patient to manipulate his wheel chair. The muscles of his upper arm had fortunately remained strong.

FIG. 5-C

This patient is now working as a mail clerk. The hook-like mechanism achieved through the tenodesis operation enables him to use the left hand in handling heavy packages. Due to the strenuous nature of his work there has been some stretching of the fixed flexor tendons. There is still spasticity in the flexor pollicis brevis and the adductor pollicis, but it is felt that this enhances the pinching strength of the thumb (Figs. 4-A and 4-B).

CASE 2. J. B., a fourteen-year-old female, had spastic hemiplegia of the left side as a result of a head injury sustained at the age of thirteen months. When first seen on June 13, 1953, she had a moderately severe contracture of all the long flexor tendons of the fingers, thumb, and wrist, and only a trace of voluntary dorsiflexion of the wrist. A two-stage operative procedure was carried out. At the first stage on October 14, 1953, all the wrist and long digital flexor tendons except the flexor pollicis longus were severed so that the wrist could be brought into dorsiflexion. The brachioradialis was then transferred to the extensor carpi radialis brevis. Following this operation, she obtained about 70 degrees of wrist motion. At the second-stage operation on July 21, 1954, all the tendons of the flexor digitorum profundus were fixed to the radius.

She is now able to perform many household activities which require the use of two hands, including washing dishes and sweeping the floor.

CASE 3. R. D., a male, thirty-five years old, contracted acute poliomyelitis in October 1952 and suffered severe paresis of the right hand, the trunk and the lower extremities. He retained strong radial wrist extensors and a good brachioradialis, but the remaining muscles of the forearm and hand were completely flail. On August 4, 1954, all the tendons of the flexor digitorum profundus were fixed to the radius to provide automatic grasp. The extensor pollicis brevis was rerouted across the palm and fixed to the ulna for opposition. In order to enhance the pinch mechanism, the brachioradialis was transferred to the flexor pollicis longus.

When last seen he was able to use the right hand to propel himself in a wheel chair and to hold objects, such as an electric razor, mirror, or book (Figs. 5-A, 5-B, and 5-C).

CASE 4. N. N., a seventeen-year-old male, had paralysis of the extremities below the sixth cervical

vertebra as a result of an automobile accident. Examination revealed that the upper extremities were flail below the shoulders except for the presence of a strong biceps brachii, brachioradialis, and pronator teres and good radial wrist extensors. Operation on the right arm was carried out in August 1954, at which time the tendons of the flexor digitorum profundus to the long, ring, and little fingers were fixed to the radius. The pronator teres was detached, prolonged by means of a tendon graft and sutured to the tendon of the flexor digitorum profundus of the index finger in order to provide voluntary flexion of this digit. The brachioradialis was transferred to the flexor pollicis longus in order to give pinch (Figs. 6-A through 6-D).

This patient's chief avocation was that of a marksman. For this reason an attempt was made to give him a "trigger finger" by making possible individualized voluntary flexion of the index finger. At the present time he is able to fire a revolver with a fair degree of accuracy and has obtained a surprisingly strong automatic grasp as well as a voluntary pinching mechanism.

DISCUSSION

The most valuable function regained by most of these patients appeared to be the power of grasp. This power was greatest in those patients who possessed a strong radial wrist extensor. The use of the brachioradialis as a wrist dorsiflexor has two disadvantages. Since the brachioradialis crosses the elbow joint, its power is greatest when the elbow is extended and weakest when the elbow is flexed. Thus, when the hand is brought toward the face in the hand-to-mouth function, the grasp weakens. The second disadvantage is

FIG. 6-A

FIG. 6-B

Fig. 6-A: Case 4. The position of the fingers upon maximum palmar flexion of the wrist.

Fig. 6-B: The fork is held between the index and long fingers, with the overlapping thumb providing stability.

that the brachioradialis cannot function effectively as a wrist dorsiflexor unless the elbow is stable. In a case not reported in this paper, a poor range of wrist motion was evident because of loss of the triceps brachii and consequent instability of the elbow. This patient could dorsiflex the wrist only when the elbow was held in extension by the opposite hand.

The presence of a contracture of the long extensor tendons may be a disadvantage. When the wrist is in palmar flexion, the tight extensors increase the clawing of the fingers and make it more difficult for the patient to open the hand in order to pick up objects. However, an already present or surgically produced contracture of the intrinsic extensor-tendon apparatus may be of value. Although such an operation has not yet been done by the author, it is possible that a modification of Riordan's intrinsic-extensor tenodesis operation would prove useful. Riordan has utilized slips of the wrist extensor tendons to prevent hyperextension of the metacarpophalangeal joints. The ends of the tendon slips which insert into the base of the metacarpals are left attached; the other ends are then passed distally through the interosseous spaces into the digits and are sutured to the radial portion of the extensor aponeuroses. If these slips were left attached to their respective tendons proximal to the wrist joint and then passed into the fingers, it would appear that automatic intrinsic extension of the fingers should occur when the wrist was palmar flexed. Figure 6-A illustrates a case in which loss of extension of the interphalangeal joints has compromised the patient's ability to open the hand.

The degree to which the fixed flexor tendons will stretch seems to depend upon the type of use to which the hand is put. In Case 1, the hand was used rather strenuously in the handling of heavy packages and maximum pull was placed upon the tendons while the fingers were used as a hook. Two and one-half years after surgery the finger tips lacked about two inches of touching the central palmar crease when the wrist was in maximum dorsiflexion. In this patient the grasping power was lost except for large objects. In all of our cases, the fixed tendons were made tight enough at the time of surgery to bring the finger tips into contact with the palm when the wrist was in maximum dorsiflexion.

The use of secondary tendon transfers to provide some measure of voluntary control will give the patient confidence in his ability to use the hand. Purely automatic motions are awkward, and considerable practice and occupational therapy are required before maximum value is obtained. If the thumb can be brought against the side of the finger at will rather than automatically, the utility of the pinching mechanism will be increased.

FIG. 6-C

FIG. 6-D

Fig. 6-C: The patient's ability to grasp a hammer was adequate, but his ability to manipulate the tool was poor due to the loss of lateral wrist motion.

Fig. 6-D: The trigger finger could be partly flexed automatically by wrist dorsiflexion. Further flexion could be achieved voluntarily as the result of the pronator teres transfer.

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DISCUSSION

DR. DANIEL C. RIORDAN, NEW ORLEANS, LOUISIANA: I agree with Dr. Wilson that too many surgeons fuse wrists too early. I think that his paper is a very timely presentation and that we are fortunate in having this useful procedure brought to our attention.

Dr. Wilson has not made any claim that this was an original procedure, and he points out that Bunnell laid down the essential principles and necessary requirements in his book *Surgery of the Hand*. Fortunately, the indications for doing this procedure are not commonly encountered, as few hands and forearms are so severely disabled that automatic function has to be relied upon. When there are only one or two muscle motors available, however, this procedure, in my opinion, definitely should be chosen in preference to a procedure involving wrist fusion. I agree with Dr. Wilson that wrist fusion should be done last, if it is necessary, and not first.

Dr. Wilson pointed out the limitations of this procedure and also pointed out that some fixed tendons do stretch if they are put to very strenuous use. In spite of this, patients upon whom such a procedure has been done are grateful for gaining the ability to make a reasonably good fist.

Speaking from personal experience, I can state that tenodesis of the tendons that pass across the metacarpophalangeal joints does help considerably to prevent clawing of the fingers in the occasional patient who

has marked hyperextension of the metacarpophalangeal joints when the wrist is flexed. The tendons may be made to cross the wrist joint if they are not stripped down to their insertions. We have even done this type of tenodesis on children and have not found that the fixed tendons become too short as the child grows. I do not know the optimum age at which this operation can be done, but the youngest patient upon whom we have performed it was five years old. A three-year follow-up in this case has not revealed any tendency for the condition to become progressively worse. Spastic patients may have tight or spastic intrinsics, which will prevent clawing of the fingers. Arthrodesis of the metacarpophalangeal joints of the thumb may be done to offset spastic flexion contracture.

Dr. Donald R. Pratt, San Francisco, California: The planning of surgical treatment for patients with paralysis, whether flaccid or spastic, demands careful consideration of all possible methods of treatment and of the results to be obtained by each method. If we fuse a wrist and thereby rob the patient of automatic motions, his condition will be worse. If there are sufficient tendons available and we resort to tenodesis, we will not provide strength and stability. The indications for tendon transfer, tenodesis, and arthrodesis differ in the upper and lower extremities. The hand needs mobilization and the foot, stabilization. Some tendon transfers are useful in the foot, but are even more effective in the hand. Tenodeses are practical in the hand as it is not a weight-bearing structure, but in the foot, unless massive in extent, they do not hold up. Arthrodesis is most useful in the foot because it provides stability. In the upper extremity it can be used to stabilize the arm proximal to the portion which can still be voluntarily activated. Better function of the distal parts may be thus obtained.

In planning tendon transfers, one should determine the number of actions needed and the number of muscles available and match them to best advantage. When there are too few muscles available, either arthrodesis or tenodesis may be the best procedure. When arthrodesis is done, enough joints should be fused so that the few remaining tendons can provide prehension. When only one strong wrist mover is available, tenodesis can provide the hand with the ability to open for grasp and can provide the fingers with the ability to close for grasp and to oppose the thumb. These principles have been adhered to for many years by Dr. Bunnell and his staff. In our files I have found several dozen cases in which tenodesis was performed.

In our experience satisfactory function following tendon transfers depends upon the presence of adequate muscle strength. In tenodeses about the wrist, a strong active wrist dorsiflexor is important. It has been found better to make both tendon transfers and tendons that are fixed to bone a little on the tight side. Tenodesis can provide effective opposition of the thumb. As a supplement to tenodesis of the wrist, active muscles can be sutured to the fixed flexor tendons of the thumb and index finger distal to the point of bone attachment in order to provide some voluntary flexion of either the thumb or index finger or of both.

The principle of tenodesis has long been known. Often it occurs spontaneously in patients with cicatrix or paralysis. Either the flexors or extensors of the digits become adherent in the forearm, resulting in automatic motions which provide good function.

Dr. Wilson (closing): The same reservations which apply to arthrodesis of the wrist also apply to arthrodesis of the phalangeal and other joints in the hand.

Dr. Riordan mentioned fusing the proximal joint of the thumb in patients with spastic flexion contractures. In the patients in our series residual spasticity in the thumb did not necessarily constitute a liability. Some patients can use the normal hand to extend and abduct the spastic thumb. Then, when an object is grasped, the spastic thumb clamps down upon it to provide a very firm hold.

I am not sure that we should attempt to perform neurectomy on spastic muscles, thus rendering them functionless, unless they can be shown to serve no useful purpose.

Chondrosarcoma, A Surgical and Pathological Problem

Review of 212 Cases *

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A gradual evolution in the thinking and, consequently, the treatment applied to cartilaginous tumors and, particularly, the malignant cartilaginous tumors has occurred over the past fifty years. This change in attitude and subsequent change in the philosophy of treatment have occurred because of better understanding of the natural history of the disease. In the early part of the century, neither the surgeon nor the pathologist understood the basic, deadly nature of these relatively uncommon tumors. The slow growth and long interval of time between recurrences in many cases of chondrosarcoma made short-term follow-up of little value in understanding the basic nature of this tumor. Because of the subtle histological changes necessary for predicting a malignant clinical course, surgeons with large experience in neoplasms of bone learned of the serious nature of large chondromatous tumors before their colleagues in the laboratory. Gradually, correlation between the histopathological nature and the clinical behavior of hyaline-cartilage neoplasms has led to the establishment of criteria for predicting their malignant course [6, 10]. Even in recent years, however, experienced observers emphasize the difficulties in diagnosis of some of the "borderline" lesions [11]. In the past twenty-five years or more there has been increasing emphasis on prompt diagnosis and early, radical, definitive surgical treatment of proved chondrosarcomata. Our study of 212 cases of chondrosarcoma of the trunk and extremities in which surgical procedures have been performed at the Mayo Clinic in the period 1905 to the present time (1955) clearly demonstrates this evolution in diagnosis and treatment.

Study of the pathology of these tumors was facilitated by having the preserved gross specimens available for review. New microscopic sections were procured as required. The clinical course of the disease in all these cases was then studied in an attempt to establish a pattern to explain the natural history of the disease and also to evaluate the results of treatment.

INCIDENCE

These 212 cases constitute less than 10 per cent of the pathologically verified primary neoplasms of bone in our collection. Chondrosarcomata constituted 7.6 per cent of the primary malignant bone tumors in the Registry of Bone Sarcoma of the American College of Surgeons [12]. In our experience, chondrosarcoma is twice as common as Ewing's tumor and half as common as osteogenic sarcoma.

Eighty of the patients had had their original treatment elsewhere, and they had recurrent lesions when they came to the Mayo Clinic. Thus the high percentage of referred patients would tend to make the incidence of chondrosarcoma seen at the Clinic relatively high.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, February 2, 1956.

† The Mayo Foundation, Rochester, Minnesota, is a part of the Graduate School of the University of Minnesota.

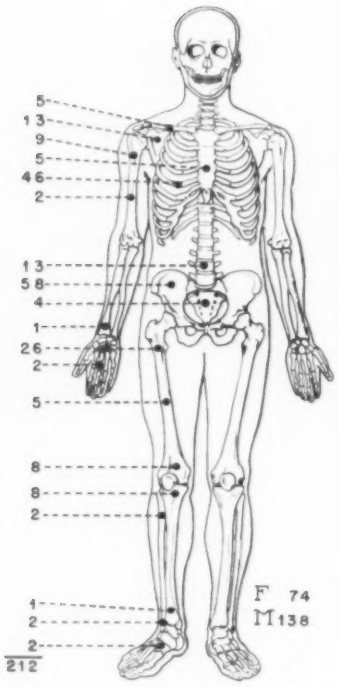

FIG. 1

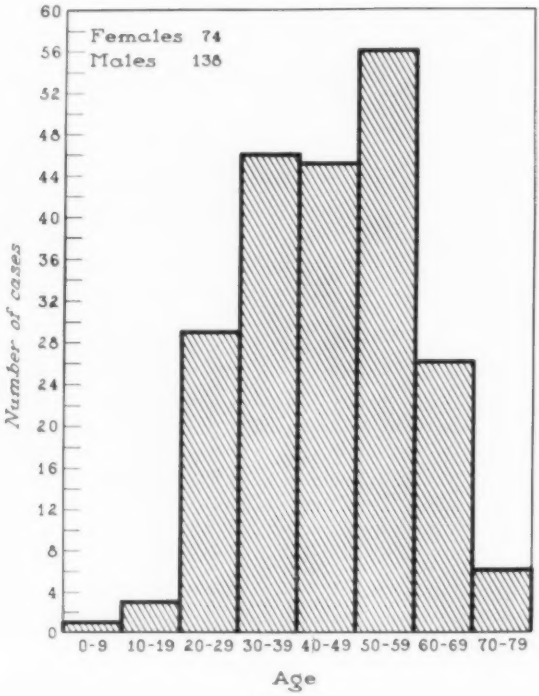

CHART I

Fig. 1: Anatomic distribution of chondrosarcomata.
Chart I: Distribution of chondrosarcomata according to age of patients.

LOCALIZATION

The anatomical distribution of these chondrosarcomata is shown in Figure 1. More than half of the tumors occurred in the pelvic girdle and ribs; 84 per cent were found in the trunk and the upper ends of the femora and humeri. There was a strikingly low incidence of malignant tumors of cartilage in the peripheral portions of the extremities—only four tumors in the hands and feet.

CLINICAL FEATURES

Of the 212 patients, 138 were male and seventy-four were female. The age distribution at the time of the first surgical treatment at the Mayo Clinic is shown in Chart I. The peak incidence was in adulthood and old age. One patient, a nine-year-old girl, was in the first decade of life; only three patients were in the second decade.

Local pain and swelling, alone or in combination, are the usual presenting complaints. Except for some of the tumors of the pelvic girdle, in which referred or local pain may precede discernible physical or roentgenographic findings, localization of these tumors is easy. As in other osseous lesions, the character of the pain or swelling offers little differential diagnostic aid. Laboratory procedures likewise add little if any diagnostic information. Roentgenographic examination is helpful.

The protracted clinical course, so often observed, affords a diagnostic clue. Patients with chondrosarcoma arising in the cartilaginous cap of an osteochondroma may have noted a gradually enlarging tumor for periods ranging from one to two decades, or more. Secondary chondrosarcoma often produces rapid increase in size of a tumor of long duration. Even patients with central sarcoma may have had symptoms for several years before

FIG. 2

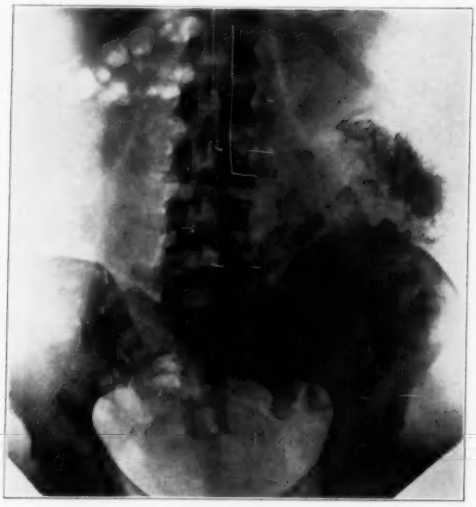

FIG. 3

Fig. 2: Chondrosarcoma of upper part of femur. There are some expansion of the shaft, thickening of the cortex, and slight calcification in the medullary area.
Fig. 3: Chondrosarcoma of left ilium exhibiting extensive calcification.

seeking medical advice. Patients with inadequately treated tumors have a typical history of many recurrences and, finally, of huge extensions of the tumor that lead to death. A minority of pure chondrosarcomata run a much more rapid clinical course because of a higher degree of either initial or secondary malignant growth. In eleven of our 212 cases metastasis occurred within two years of the first surgical procedure, and in nine of these there had been preoperative symptoms of less than three years' duration. In many other cases in which metastasis apparently did not occur, the growth was so rapid that the interval between onset of symptoms and death was less than ten years.

Good evidence of metastasis was obtained in less than 10 per cent of the 212 patients. In most of them, metastasis was to the lungs by way of the blood stream, although in two patients there was metastasis to the regional lymph nodes. Exact information on metastasis is unavailable because necropsy was performed in so few cases. A review of the records indicates, however, that local recurrences were responsible for death in most of the unsuccessfully treated patients.

ROENTGENOGRAPHIC FEATURES

The roentgenogram frequently affords helpful diagnostic evidence when one is confronted with a chondrosarcoma. Destruction of bone and mottled calcification at the involved site are the most common findings. Many of the central tumors of long bones produce a fusiform expansion of the shaft associated with thickening of the cortex (Fig. 2). This picture, associated with cortical destruction or with mottled or fuzzy calcification within the tumor, is especially characteristic. Chondrosarcomata that do not involve the medullary cavity may show only slight peripheral cortical destruction or none at all, but they usually contain minute or massive tell-tale calcific masses (Fig. 3). Chondrosarcomata that show no calcific shadows or mottling are usually not at all distinctive roentgenographically, even though they may produce changes of a malignant character. When a benign osteochondroma undergoes malignant transformation it loses its uniformity and its regular borders, these being replaced by a more or less densely calcified irregular tumor.

FIG. 4

FIG. 5

Fig. 4: Gross specimen from case illustrated in Fig. 2. Typical central chondrosarcoma of upper part of femoral shaft extending into neck.

Fig. 5: Central chondrosarcoma showing cortical expansion and thickening and extra-osseous extension.

PATHOLOGICAL FEATURES

It is customary to divide chondrosarcomata into central and peripheral types according to location, and to divide them further into secondary and primary types according to the existence or absence of a pre-existing benign neoplasm.

Central and peripheral tumors are ordinarily readily distinguished when they affect the large tubular bones, where the central variety predominates. As seen in roentgenograms, these central tumors often produce expansion of the bone (Fig. 4). Even though there is thickening of the infiltrated cortex at the affected site, the more advanced tumors burst through to form an extra-osseous mass (Fig. 5). Grossly, the site of marrow involvement is discreetly demarcated in the average case. In our series, the exact site of origin of the peripheral chondrosarcomata, aside from those complicating osteochondromata, could not be determined. Minimal to considerable cortical destruction had occurred in the patients by the time of surgical intervention.

Chondrosarcomata arising in small bones, such as ribs, or in flat bones, such as the innominate, are probably most often of central origin. In our series, however, by the time the tumors were studied pathologically they were of such size that one could not prove where they arose.

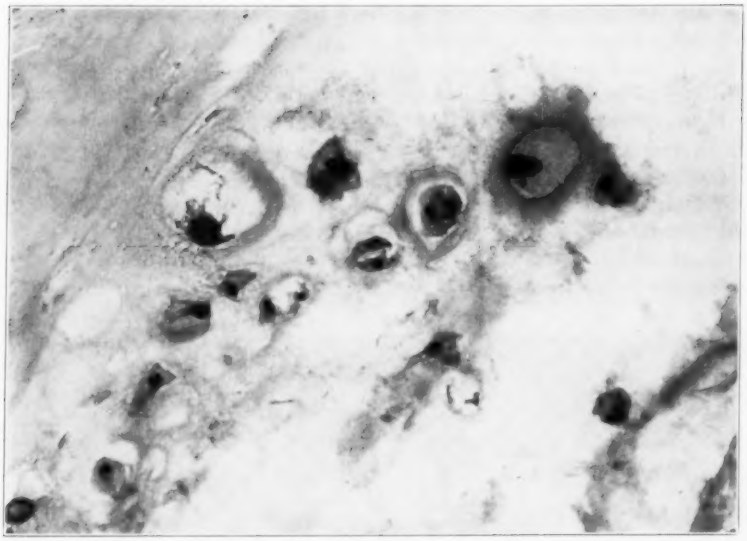

FIG. 6

Typical cytological features indicating malignant growth. They include large, hyperchromatic nuclei and binucleate cartilage cells (hematoxylin and eosin, × 350).

Secondary chondrosarcoma complicates benign osteochondroma and enchondroma. Regarding osteochondroma, a history of prolonged existence of a tumor that suddenly takes on active growth provides strong circumstantial evidence of malignant transformation. This can be proved if the chondrosarcoma has not completely destroyed the typical benign osteochondromatous pedicle or base. In our series, there was clinical or pathological evidence that nineteen of the 212 chondrosarcomata arose in osteochondromata. Twelve of the nineteen occurred in patients who had the familial disease characterized by the occurrence of multiple osteochondromata.

Chondrosarcoma secondary to proved benign enchondroma was not encountered in this series. Study of original specimens, which included all of those that had been removed at the Mayo Clinic and many of the eighty that had been removed elsewhere, revealed cytological evidence of malignant growth in each instance. In each, a malignant clinical course should have been suspected from study of the histological sections. It is true that in several instances the primary tissue was sufficiently "borderline", in respect to malignant growth, that one might well have hesitated to recommend extensive ablative surgery. In some cases, only small areas within the original tissue exhibited the cytological changes indicative of malignant change.

Grossly, the chondrosarcomata varied from myxomatous, semiliquid tumors to very firm lobulated masses of hyaline cartilage, showing slight to marked calcification and ossification. Cystic degeneration was sometimes prominent and this, like the calcification, tended to involve the central portions of the neoplasm. The consistency of the tumors did not appear to have a significant bearing on prognosis.

Histological criteria in the diagnosis of chondrosarcoma have been developed on the premise that a strong tendency to recur and to kill by local extension is sufficient evidence of malignant growth. The features indicative of malignant growth observed in viable, noncalcified areas were outlined by Lichtenstein and Jaffe. These features include the presence of (1) many cells with plump nuclei, (2) more than an occasional cell with two such nuclei, and (3) any giant cartilage cell with single or multiple nuclei (Fig. 6). These features are

invaluable in assessing the relatively well differentiated chondrosarcomata, but, by their very wording, they demand the acceptance of a group of tumors that one must regard as "borderline" for malignant growth. Obviously, the percentage of lesions that one regards as "borderline" will decrease as one's experience increases. In the more highly malignant minority of chondrosarcomata, the triad of criteria listed previously give way to obviously malignant characteristics. Calcification may occur in areas of degeneration (Fig. 7), and ossification may result from differentiation of the hyaline cartilage.

In our study, we attempted to tabulate the degree of malignant growth. Accordingly, the tumors were graded one to three on the basis of their cytological appearance (Table I). Nuclear pleomorphism, hyperchromatism, and increased number of multinucleated cells were the important features indicative of greater cytological activity, and these features

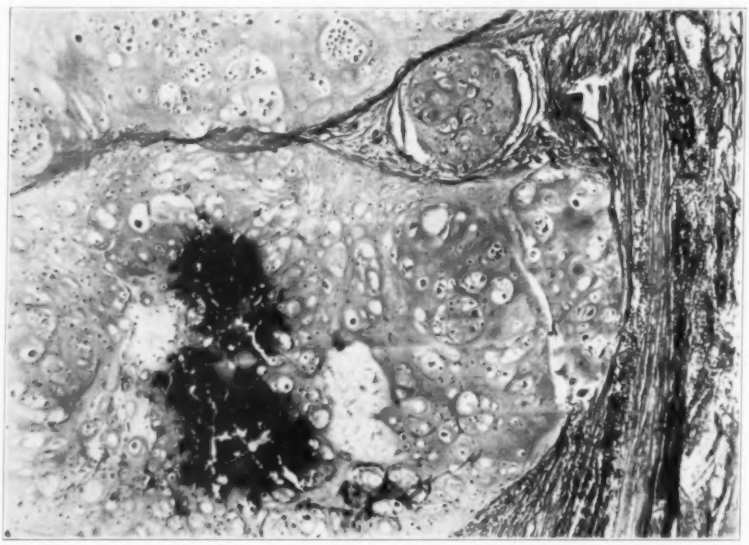

FIG. 7

Black zone indicates calcification in degenerating central part of chondrosarcomatous lobule (hematoxylin and eosin, × 47).

were used in grading. Such a tabulation may have questionable value, but the grades did show some correlation with prognosis. The predominance of a low degree of malignant growth was also observed by O'Neal and Ackerman.

An increasing degree of malignant growth with recurrence has been considered a problem in the management of chondrosarcoma. In this series, increased cellular activity sufficient to change the numerical grade was observed in thirteen of the recurrent tumors. In eight of these, the periphery of the lobules of the recurrent lesions showed a spindling of the tumor cells, in some instances resulting in areas of frank fibrosarcoma. In two recurrent tumors showing increased activity, zones of osteogenic sarcoma were found. The histological changes in these thirteen cases were accompanied by a clinical course that included the development of distant metastasis in several instances.

Permeation of bone at a site away from the obvious gross edges of a central cartilage tumor was often observed in amputated specimens. This accounts for the recurrence that routinely follows curettage for chondrosarcoma. In one case the thickened, expanded cortex of the upper part of the femur, surrounding a Grade 2 chondrosarcoma, was infiltrated by a spindling fibrogenic tumor. Despite no obvious contamination of the

wound by tumor at the time of hip disarticulation, which seemed an adequate operation, the patient returned in a year with a huge Grade 3 fibroblastic osteogenic sarcoma (Fig. 8) that had recurred in the scar.

TREATMENT AND RESULTS

In an attempt to evaluate the results of treatment, we set up criteria for what we considered to be adequate or ideal surgical treatment, so that we could compare the course in the patients who had not had such treatment with that in those who had been treated properly. The differences in surgical treatment in this series are accounted for by several factors. Eighty patients with recurrent tumors had had the original treatment elsewhere. Before the nature of chondrosarcoma was fully realized, curettage and cautery seemed to be the most logical form of treatment. Furthermore, many of these tumors were inaccessible surgically, either because of size or because of location.

TABLE I

DISTRIBUTION OF CASES OF CHONDROSARCOMA ACCORDING TO DEGREE OF MALIGNANCY

Grade of Malignant Growth	Cases	Per cent
"Borderline"	4	1.9
1	116	54.7
2	79	37.3
3	13	6.1
Total	212	100.0

We have arbitrarily set up the following standards for proper surgical treatment:

1. An adequate biopsy specimen should be obtained. This specimen should consist of sufficient material to give the pathologist at least a reasonable chance to make an accurate diagnosis. If the diagnosis can be made on a fresh frozen section of material, the surgical area is then prepared with the usual solutions and the area is redraped. The surgical team changes gowns and gloves, and the biopsy instruments are discarded.

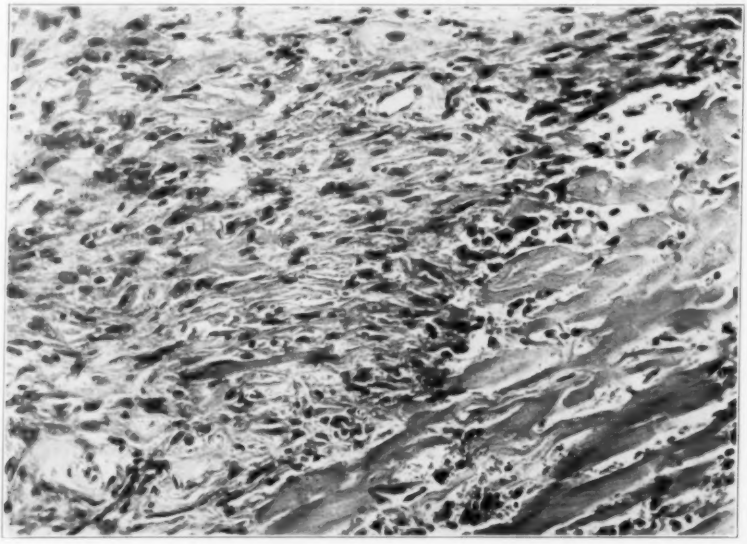

FIG. 8

Grade 3 fibroblastic osteogenic sarcoma. Recurrence in scar after amputation for Grade 2 chondrosarcoma with fibrosarcomatous elements permeating surrounding cortex (hematoxylin and eosin, × 185).

2. The definitive operation that is then carried out is performed in such a manner that the biopsy wound will be excluded from the incision and will be removed with the specimen or the limb, or both, without being opened again.

3. The tumor itself should be completely excised with a zone of surrounding tissue so that the surgeon does not break into or see the tumor at any time.

In 139 of the 154 patients in whom there were recurrences after the original surgical procedures, the longest interval between two consecutive appearances of the tumor was less than five years. In fourteen others, the longest such interval was five to ten years and in only one case was the interval more than ten years. With these figures in mind, it seemed that we should insist on a ten-year symptom-free period of survival before presuming the patient to be cured.

Exclusive of five who died in the postoperative period, 207 patients remained. Of the 207 patients, 122 were considered to have had inadequate treatment and eighty-five were considered to have had adequate surgical treatment. Nine of the 122 patients in the first group could not be traced and four others had the last surgical treatment within ten years. Of the remaining 109 patients, four have gone more than ten years without a recurrence and are considered to be cured. Eighty are dead as a result of the disease, and an additional twenty-five have had massive recurrence and are also considered failures of treatment. In the group in whom surgical treatment was inadequate, then, there were only four successful results in 109 patients, or a percentage of 3.7. Of the group of eighty-five patients who underwent adequate surgical treatment sometime during the course of their illness, fourteen could not be traced and an additional thirty-seven have had their definitive surgical treatment within the last ten years. Of the thirty-four patients traced who are eligible for determination of ten-year survival, fourteen are alive and well, showing that adequate therapy has resulted in a successful outcome in 41 per cent of the patients traced.

Our data do not justify a comparison of the results of treatment of the primary chondrosarcoma and secondary chondrosarcoma. Of interest is the fact that three patients with tumors involving the iliac crest were cured by radical resection that spared the hip joint and the lower extremity. These may all have been fortuitous cures, because one patient required ten operations for local recurrences between the years 1912 and 1935 and is alive and well at the present time. The other "cures" of lesions of the iliac crest represent two of the four "borderline" tumors in this study.

Further study of these tumors indicates that those that appear more active microscopically are associated with somewhat poorer results. In the eighteen patients in whom we have considered the results successful after long-term follow-up, there were only two tumors in which the grade of malignant growth was higher than Grade 1. In the 125 patients in whom we have considered the results unsuccessful, there were fifty-six tumors in which the grade of malignant growth was higher than Grade 1. In the thirty-three patients in whom metastasis occurred, there were twenty-five instances of pulmonary metastasis, three of metastasis to the spinal column, three of apparent metastasis in the abdomen (one of these was also associated with pulmonary metastasis), and three of metastasis to the regional lymph nodes. In four of these, there was what was described as generalized metastasis. Of the tumors that metastasized, fourteen were Grade 1, fourteen were Grade 2, and five were Grade 3.

Implantation of these sarcomata was commonly observed. Such was the usual cause of recurrence in the patients treated inadequately. In other patients, implantation occurred in biopsy or other incisions (Fig. 9). Fifty-eight patients received x-ray therapy and fifteen of these seemed to derive definite benefit in that the tumors regressed in size and the symptoms were somewhat relieved. However, in none of these did x-ray treatment alter the ultimate course of the disease. Coley's toxin was used in three patients, radium was used in eight patients, and bismuth and iodine were used in two

TABLE II

COMPARISON OF ANATOMICAL DISTRIBUTION OF CHONDROSARCOMATA AND CHONDROMATA

Site of Tumor	Chondrosarcoma		Chondroma	
	Number	Per cent	Number	Per cent
Pelvic girdle	62	29 2	4	4 0
Ribs and sternum	51	24 1	3	3 0
Scapula and clavicle	18	8 5	3	3 0
Vertebrae	13	6 1	4	4 0
Femur	39	18 4	13	13 3
Tibia and fibula	13	6 1	1	1 0
Humerus	11	5 2	6	6 1
Radius and ulna	1	0 5	1	1 0
Hands and feet	4	1 9	64	64 6
Total	212	100 0	99	100 0

patients; these drugs did not significantly alter the course of the disease in any instance.

DIFFERENTIAL DIAGNOSIS

Benign Chondroma

Benign chondromata may occur centrally in bone or they may occupy a periosteal location [9]. Hence, in this respect they are analogous to central and peripheral chondrosarcomata. The basic histological criteria for separating the benign from the malignant have already been tabulated. Our experience emphasizes the point that the nearer a cartilaginous tumor is to the axial skeleton the more likely it is to be malignant. Cartilaginous tumors in the distal portions of the extremities, that is, the hands and feet, are almost certain to be benign, whereas those that involve the pelvic or shoulder girdles and the ribs are usually malignant (Table II). A tumor of large size (several centimeters in diameter) should be viewed with alarm regardless of its location. Although pure cartilaginous tumors in a periosteal location may show considerable cellular activity and still be benign, one must avoid the trap of underdiagnosing truly malignant tumors in this location.

FIG. 9

Recurrent peripheral chondrosarcoma of upper part of tibia. Implantation had occurred in old operative scar.

Osteochondroma

No problem in diagnosis is offered by the typical osteocartilaginous exostosis in which the central core is continuous with the underlying medullary bone, in which the outer shell is similarly continuous with the cortex of the bone of origin, and in which a regular cartilaginous cap is present. Such tumors are uniformly benign. When the cartilaginous cap is thickened to the extent of one to several centimeters, and especially if the cap is

irregular, there is the possibility of malignant transformation. The roentgenogram frequently suggests, on the basis of the irregularities produced, that chondrosarcoma has been superimposed on a benign lesion. Verification of the malignant nature of the lesion depends upon the histological criteria already described. In the phase of rapid osseous growth during childhood and adolescence, the cartilaginous cap of an osteochondroma may be somewhat thickened and it may contain binucleate cell forms in considerable number. Ordinarily, however, the nuclei are small and regular and the cartilage cells are lined up in large lacunae reminiscent of the picture seen in a normal-growing epiphyseal line. From the clinical standpoint, continued growth of an osteochondroma after the epiphyses fuse at puberty should arouse suspicion.

Chondromyxoid Fibroma

The characteristic features of this tumor were defined by Jaffe and Lichtenstein in 1948. They emphasized the likelihood that this benign process can easily be mistaken for a malignant one, especially chondrosarcoma, unless the pathologist is aware of the rather subtle histological details that characterize the lesion. These include a variable proportion of chondroid, fibromatoid, and myxoid elements. Although large nuclei and multinucleated cells may be rather numerous in some of these tumors, they are not significant. Chondromyxoid fibromata characteristically show lobulation or pseudolobulation with distinct condensation of cells at the periphery of the lobules (Fig. 10). These lesions are clearly demarcated from the surrounding bone even though some of the lobules of the tumor may project into the surrounding bone. The fact that the great majority of these tumors occur in the second and third decades of life when chondrosarcomata are relatively unusual constitutes a clinical aid in differential diagnosis. In twelve examples of chondromyxoid fibroma [3], the roentgenograms were interpreted as being indicative of a benign process in every instance, and this interpretation was based largely on the smooth and discreet contour of the rarefied defect.

Chondroblastoma

The typical chondroblastoma with large areas quite like those of a benign giant-cell tumor of bone and only occasional islands of chondroid substance offers no diagnostic problem to one familiar with the lesion. Occasionally, one encounters a tumor of this type in which large areas of cartilaginous substance are produced; these areas may simulate hyaline cartilage quite closely. In such instances, search for the cellular zones which contain benign multinucleated cells helps to solve the problem. Those chondroblastomata with prominent zones of cartilage may appear cartilaginous grossly, and the problem of differential diagnosis when dealing with a central cartilaginous tumor of the pelvic and shoulder girdle may arise. We have observed four benign chondroblastomata of the innominate bone and two of the scapula [7].

Chondroblastic Osteogenic Sarcoma

We have excluded from our series of chondrosarcomata those tumors wherein the basic proliferating malignant cells have in some areas produced a distinctly osteoid matrix, even though most of the tumor may be producing cartilage. Occasionally this differentiation is difficult to make, but ordinarily the production of osteoid tissue by malignant cells, even if in only small areas, is readily recognized. That such tumors logically belong with the remainder of the osteogenic sarcomata is emphasized by the clinically observed fact that their peak incidence is in the years of late adolescence and early adulthood. Furthermore, these chondroblastic osteogenic sarcomata have about the same marked tendency for blood-borne metastasis as do ordinary osteogenic sarcomata. Some people still call this type of osteogenic sarcoma "primary chondrosarcoma", although they admit its clinical kinship to osteogenic sarcoma [2].

COMMENT

The extremely poor prognosis of chondrosarcomata that receive inadequate treatment is emphasized in our series. Unfortunately, because of our insistence on a ten-year follow-up period, a large percentage of those receiving more radical and, hence, adequate treatment have been deleted from the survival figures. A recent study of results of hindquarter amputation by Bickel and his associates indicates that early radical operation greatly alters the previously dismal outlook of patients with chondrosarcoma of the upper part of the femur and of the innominate bones. Harrington, as early as 1927, emphasized the need for wide excision, getting well around the tumor in the case of malignant lesions of the chest wall, which are predominately chondrosarcomata.

Treatment and the valuation of its efficacy are difficult because no chondrosarcoma is anatomically exactly like any other. For example, a small chondrosarcoma confined within the upper end of the humerus might be treated successfully by resection and bone-grafting, whereas another that is similar histologically may have spread into the joint capsule so that disarticulation at the shoulder would invite the development of incurable recurrence. A seemingly favorable prognosis based on histological activity or radical treatment may be nullified by such factors as preoperative delay or the location of the tumor. If the chondrosarcoma is of a low degree of malignant growth and is located far enough from the trunk so that a recurrent lesion will be operable, one may institute conservative treatment, such as excision, recognizing that a few such tumors, when they recur, will be capable of metastasis. Malignant cartilaginous tumors in or near the trunk demand radical procedures at the first operation, because recurrent lesions in these locations are usually inoperable. In the extremities, amputation is generally the operation of choice, although occasionally, for a small tumor, block excision with replacement by bone-grafting is feasible. In the pelvis and shoulder girdles, an occasional tumor can be excised *en bloc*, but in the majority of cases radical excision is indicated. In the proximal part of the humerus, an interscapulothoracic amputation is the procedure of choice, in the proximal part of the femur, an interinnominoabdominal amputation is the procedure of choice.

Secondary chondrosarcomata certainly do occur, but in our experience they have always been secondary to osteocartilaginous exostoses. Regarding chondrosarcoma secondary to enchondroma, some workers imply that practically all central chondrosarcomata are on a secondary basis [2], whereas others suggest that approximately half of such tumors arise in a pre-existing benign process [8]. Our experience confirms the observations of O'Neal and Ackerman, who found in a study of recurrent tumors that the original tissue was never clearly benign. Even such an astute observer as Lichtenstein, when describing one of his secondary chondrosarcomata, admits that, on review of the original tissue, "we realized that we had under-diagnosed it". Too often, the pathologist is more or less forced into the diagnosis of chondrosarcoma because of the overwhelming clinical proof of malignant growth manifested by recurrence, when in reality the tumor, histologically, is not different from the original one that had been called benign. Acceptance of the idea of a secondary chondrosarcoma in the central cartilaginous lesion affords the pathologist a convenient crutch.

As indicated above, four patients in this series were cured for long periods despite what we considered to be inadequate therapy. We cannot explain the paradoxical cures on the basis of histology because the tumors under discussion were indistinguishable, microscopically, from other low-grade lesions that eventually caused death of the patients. The tumors of these four patients did have these features in common: they were peripheral in location in regard to the bone of origin, and they all were firm and had central calcification. We can only assume that all of the malignant tissue was removed by the surgeon and that, fortuitously, implantation did not occur.

There has been a growing tendency among some orthopaedic surgeons to deal radically with all cartilaginous tumors of the pelvic and shoulder girdles. This practice cannot be

condoned for several reasons. Occasionally a benign osteocartilaginous exostosis of large size, when it affects the innominate bone or the shoulder girdle, may fail to exhibit the roentgenographic features of a similar tumor of a long bone. Even though there may be some irregularity of the cartilaginous cap, histological evidence of malignant growth should be demanded before extensive ablative surgical procedures are carried out. Without histological evidence of malignant growth, such a tumor will not behave in a malignant fashion. We have observed two fairly large, but perfectly benign chondromyxoid fibromata in the innominate bones; such tumors, on gross examination, may be indistinguishable from chondrosarcomata. Of our six benign chondroblastomata involving the innominate bone or scapula [7], three had a distinctly chondroid gross appearance. An accurate diagnosis short of histological examination of such a tumor is impossible.

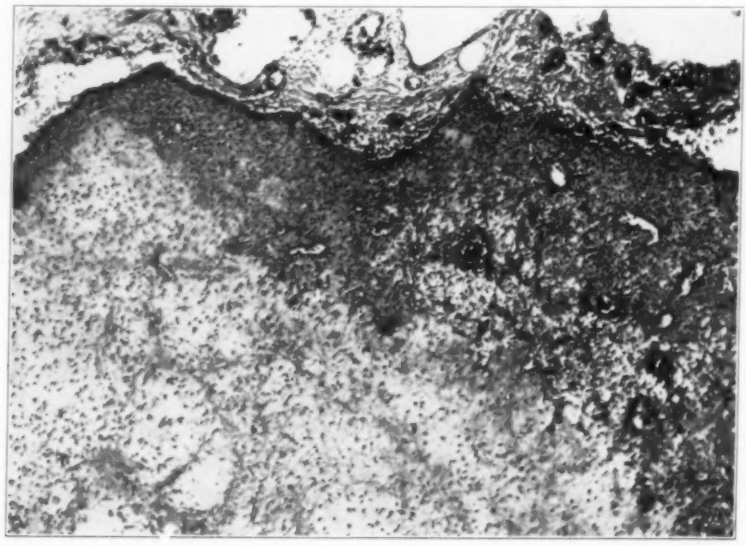

FIG. 10

Chondromyxoid fibroma. Although the cytological features of this tumor may suggest malignant growth, the lobulated, cellular, well-demarcated periphery indicates the correct diagnosis (hematoxylin and eosin. × 87).

Study of these cases emphasizes the importance of proper surgical management of proved malignant tumors of hyaline cartilage. After adequate pathological study to rule out the possibility that a given lesion is one of the benign variants that may superficially resemble chondrosarcoma, one must be prepared to do a definitive operation. If the tumor is so located that recurrence would still be amenable to surgical therapy and if the tumor is of a relatively low degree of cellular activity, local excision of the peripheral tumor may be attempted. In the case of central tumors of the long bones, block excision with placement of a graft across the site of ablation, as advocated by Phemister, may be attempted. It is well to remember that a small percentage of tumors so treated will, when they recur, be of such increased cellular activity that they are capable of metastasis. In general, however, this threat is not great enough to preclude conservative management of some of the low-grade and especially the "borderline" lesions. The concept that one has but one good chance to cure chondrosarcoma of the upper part of the femur, the pelvic bone, the thoracic cage, the shoulder girdle, and the humerus should govern the management of tumors in these locations. One should not attempt an inadequate, conservative operation.

The problem of implantation of chondrosarcoma in the operative site was amply

illustrated in this series. It became obvious to the surgeons that cure could not be expected when the tumors were broken into. The danger of implanting viable cells in the surgical or biopsy incision was emphasized by such a case as that illustrated in Figure 9. Implantation of viable cells in chondromatous tumors is perhaps facilitated by the fact that normal cartilage derives its nutrition without a direct blood supply. In several cases in our series, obvious implantation in the operative field occurred. We have observed chondrosarcoma in implants in the fibrin along the biopsy tract. The surgeon who hopes to cure a chondrosarcoma must design his operative incision so that it can be included in and discarded with the excised or amputated surgical specimen.

Curettage of central chondrosarcoma can at best be considered palliative therapy and too conservative. The fact that chondrosarcomata tend to permeate the bone surrounding the obvious rarefied defects makes it virtually impossible to cure these malignant growths by simple curettage. In fact, in some instances, the more malignant parts of the tumor may be left behind after this therapy.

As mentioned before, it is imperative to obtain adequate tissue for histological examination. Areas of necrosis or areas of relatively little cellular activity may dominate the picture in small specimens. For these reasons a negative result obtained by examination of a needle biopsy specimen obviously has no value in the face of clinical or roentgenographic evidence of one of these osseous neoplasms. In our experience, a fresh frozen section stained with polychrome methylene blue or with hematoxylin has usually afforded a definitive diagnosis on which therapy could be based. The examination of fresh frozen sections of biopsy material has the additional merit that it discloses whether the biopsy specimen is adequate. The biological behavior of these tumors is such that the delay occasioned by study of fixed permanent sections is a minor problem in the management of the patients.

Surprisingly good results in relief of symptoms and actual temporary regression of the size of the tumor have been obtained in enough cases to suggest that roentgen therapy might be worthy of further investigation as a therapeutic aid.

It should be emphasized that we do not feel that a five-year or even a ten-year survival rate has any significance as far as the cure rate is concerned. A ten-year interval without further appearance of the tumor is necessary in our opinion to establish a cure. It is important that this interval be counted from the last surgical attack on the tumor and not from the first appearance of symptoms.

CONCLUSIONS

1. Chondrosarcoma is a neoplasm of slow growth that usually kills by local enlargement but that may metastasize through the blood stream or the lymphatic system. It is important to differentiate it from the non-malignant chondromatous variants.

2. Microscopic examination of biopsy material permits prediction of malignant course.

3. Local control of the tumor by adequate surgical treatment is the chief problem in therapy. Recurrence of the tumor in the proximal part of the extremity or in the trunk represents an irrevocable failure of treatment in most cases.

4. The ease with which chondrosarcoma implants locally in surgical wounds, including biopsy wounds, constitutes a major problem in management.

5. Conclusions as to the results of treatment of chondrosarcoma that are based on follow-up periods of less than ten years after the last surgical treatment are invalid.

6. Osteogenic sarcoma with a prominent chondroid component should not be grouped with chondrosarcoma.

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DISCUSSION

C. Howard Hatcher, M.D., Chicago, Illinois: Dr. Henderson and Dr. Dahlin's excellent report of a very large series of chondrosarcomata emphasizes the comparatively high durability rate of these tumors. I think the conclusions from this study are indisputable. In the past, many of these slowly growing cartilaginous neoplasms, particularly those seen about the pelvis, have been treated too lightly. Partial excision and curettage have no place in the treatment of such tumors and may leave incurable a tumor which could have been cured by adequate primary dissection. The diagnosis of such cartilaginous tumors usually can be made from the roentgenogram with little question. At least the presence of a cartilaginous neoplasm can be recognized; the need of its excision is obvious. While the anticipation of the degree of malignant growth can be made from histological sections of many of these tumors, there are borderline cases in which decision of malignant or benign growth can be made only after careful correlation of histological appearance, roentgenographic appearance, and the past history of that tumor. Personally, I would not advocate preliminary biopsy of readily recognized cartilaginous tumors about the pelvis. I would prefer that an occasional biopsy be done—that is, removal of the entire mass without cutting into it and with as wide a surrounding margin of normal tissue as is feasible. One can then determine the degree of malignant growth through careful and prolonged histological study. The slowly growing chondrosarcomata are the most common about the pelvis. Sections of wide areas of the innominate bone can be done and functional restoration be accomplished, leaving the patient little handicapped. It is my feeling that these wide dissections offer just as good a chance of eradication of the tumor. Actually, if the tumor does not involve the iliac or femoral vessels or sciatic nerves, dissection can be done with just about as adequate removal of tumor as would be accomplished by hindquarter section. There are, of course, instances to the contrary. Similarly, about the upper end of the femur wide excisions are possible with restoration of function by bringing the femoral shaft into contact with uninvolved ischium. The use of roentgen therapy in cartilaginous tumors in our experience has been entirely unsatisfactory. It may slow down the growth of a cartilaginous mass and may increase the calcification within tumor cartilage, but it cannot eradicate the neoplasm. The use of roentgen therapy for such neoplasms, which are surgically resectable, is deplorable because it not only does not cure the tumor but it makes any attempt at future surgery very difficult and hazardous. The roentgen scarring about the tumor may make the section difficult or impossible. Degenerated tissue, caused by radiation, is very prone to break down and result in uncontrolled infection.

Dr. Dahlin (*closing*): It certainly is true that when a tumor has been treated as radically as these chondrosarcomata frequently are, it is important to be sure of correct diagnosis before proceeding further. There are five conditions that I would like to consider in the differential diagnosis. The first is chondroma. Benign chondromata may be central in regard to the shaft of the bone, they may be peripheral, or they may be periosteally located. They are usually small in contrast with chondrosarcomata. Calcification appears in either variety. Skeletal localization is helpful statistically in making a guess as to type. Roentgenograms have been extremely valuable in determining the destructive qualities of chondrosarcomata. In a chondroma each of the cells contains one nucleus; rarely is a binucleus formed. The individual cells are small. The ordinary osteochondroma gives the orthopaedic surgeon little cause to worry. It has a thin regular cartilaginous cast surrounding its bony core. When, however, the tumor has a thick irregular cartilaginous cast which is visible grossly in surgery and visible frequently in the roentgenograms as irregular calcification or when in such tumors the rate of growth has increased, malignant growth should be suspected. In determining the degree of malignant growth of these tumors and chondrosarcomata, the ordinary histological criteria apply.

A tumor that needs to be better understood, I believe, is the chondromyxoid sarcoma. Although this tumor is benign and can be cured by curettage or excision, it is frequently overdiagnosed. Generally, it

(Continued on page 1125)

Periodic Benign Synovitis

Idiopathic Intermittent Hydrarthrosis

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Periodic benign synovitis is characterized by the regular cyclic recurrence of articular disability without known provocation or systemic reaction. The terms *hydrops intermittens articulorum*, *intermittent hydrops*, *intermittent hydrarthrosis*, *chronic synovitis*, and *allergic synovitis* have all been used to describe this disease. In 1948 Reimann[13] suggested that the name *periodic disease* be used for a variety of enigmatic maladies which have in common regularly recurring cycles of symptoms. He proposed that each disorder be referred to by the name of its outstanding clinical feature, for example, periodic fever, periodic abdominalgia or periodic neutropenia[14]. Periodic articular disease or "periodic arthralgia", as he called it, is one of the better known maladies of this type, approximately 130 cases having been reported by 1955. The authors have adopted the term *periodic benign synovitis* for this condition for reasons which will become apparent later.

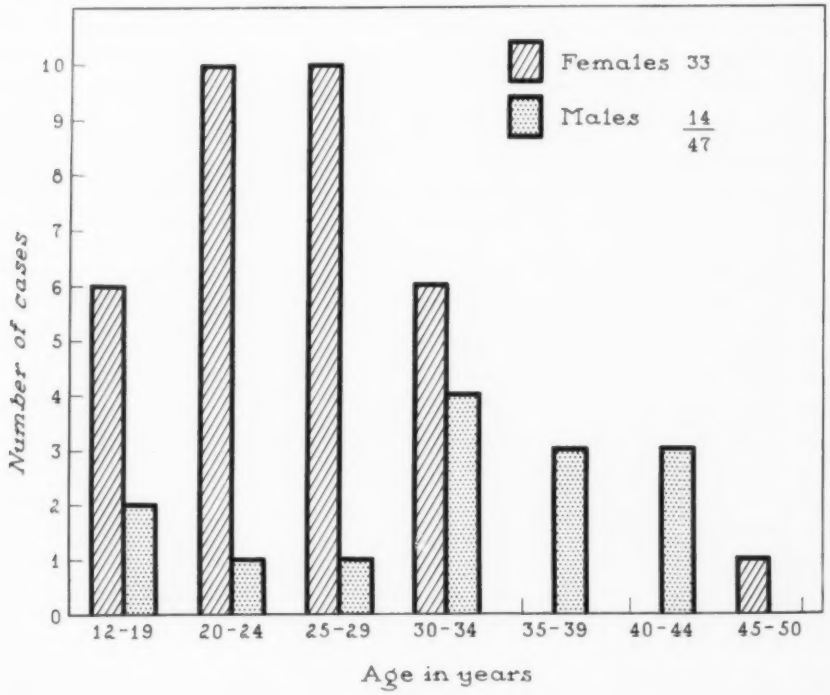

Chart I

Sex of patients and age at onset of periodic benign synovitis.

* The Mayo Foundation, Rochester, Minnesota, is part of the Graduate School of the University of Minnesota.

TABLE I

Case No.	Age at Onset and Sex	Joint Involved: Primarily	Joint Involved: Occasionally or Secondarily	Sedimentation Rate (*Westergren*): Time of Test in Relation to Attack	Sedimentation Rate (*Westergren*): Result (*Millimeters in One Hour*)
1	M 38	Left knee, hip	Occ. elbow, jaw	2nd day	2
2	F 23	Left knee	Occ. shoulder	1 week before	30
3	F 27	Knees			
4	F 30	Right knee	Occ. left knee	2 days before	9
				1st day	10
5	M 41	Knees			
6	F 28	Left knee	Occ. right knee	1942; interval *	80
7	F 24	Right knee	Occ. left knee		
8	M 41	Hands and feet			
9	F 29	Knees alternately		During attack	6
10	F 33	Right knee		3rd day	10
11	F 25	Knees		During attack	19
12	F 14	Left hip		1953; interval	11
13	F 25	Left knee	Right knee (1 year)	1951; during attack	8
				1953; during attack, mild hypercortisonism	106
				1954; interval	7
14	F 26	Knees	Shoulders	1941; during attack	20
15	M 30	Right knee		1937 and 1945	11; 10
16	F 23	Right knee	Elbow (1 year)	1939; during attack	26
				1949	42
				1952; 2½ weeks after abdominal operation	53
17	M 19	Right knee	Left knee	1938; during attack	10
				1942; during attack	11
18	M 37	Knees		Middle and 1st day	4; 4
				Interval	5
19	F 14	Right knee		1937; interval	12
				1941	9
20	F 15	Knees		1st day	8
21	F 45	Right knee		Day before	23
				2nd and 4th day	22; 26
22	F 22	Hands and feet	Knee	1938 and 1940; interval	3; 3
23	F 33	Left knee	Right knee	1938; during attack	4
				1949; interval	16
				1952; during attack	21
24	F 34	Right knee		2 days before	25
25	M 32	Right knee	Occ. shoulder	Remission?	23
26	F 22	Right knee		During attack	2
27	M 33	Left knee			
28	F 22	Left knee	Occ. left ankle	2 days before	22
29	M 34	Left foot	Occ. elbow, knee	Interval	21
30	F 15	Knees		5–7–42; during attack	18
				5–27–42; abortion of attack (histamine desensitization)	23
31	F 20	Knees		Interval	23
32	F 24	Right knee		Last day	3
33	F 30	Knees		Interval	4
34	F 31	Right knee	Occ. jaw, left knee	End of attack	26
35	F 27	Knees	Elbow (1 year)	1944 and 1945; interval	13; 5
36	F 28	Right knee		End of attack	23
37	F 13	Knees		Interval	5
38	F 17	Knees		During attack	23

TABLE I (*Continued*)

Case No.	Age at Onset and Sex	Joint Involved: Primarily	Joint Involved: Occasionally or Secondarily	Sedimentation Rate (*Westergren*): Time of Test in Relation to Attack	Sedimentation Rate (*Westergren*): Result (*Millimeters in One Hour*)
39	M 35	Left knee		3rd day	1
40	F 22	Right ankle		Remission	3
41	M 28	Right knee		1947; mid-attack	11
				1950	5
42	M 23	Knees		During attack	18
43	F 27	Knees	Occ. elbow, hip	End of attack	19
44	M 41	Left knee	Occ. right knee	1950; 1st day	39
				1953; during attack	17
				1955; early during attack	15
45	F 25	Left knee		Interval	18
46	F 21	Knees	Occ. ankle		
47	M 15	Hip and ankle		Interval	6

* Interval: symptom-free period between attacks.
† Remission: attacks seem to have ceased.

It was hoped that a review of some of the cases encountered at the Mayo Clinic would provide more insight into the common features of the disease, its general pattern, and its response to therapy. Accordingly, the authors reviewed the records of approximately 1,800 patients who had been seen at the Clinic during the twenty-five years from 1930 through 1954 and for whom at least one of the following diagnoses had been made: intermittent hydrops, intermittent hydrarthrosis, chronic allergic arthritis, chronic synovitis, palindromic rheumatism, migraine equivalent, and arthralgia. From these 1,800 cases the authors selected the ones which met the following diagnostic criteria: (1) recurrence of articular symptoms at regular intervals; (2) complete freedom from signs and symptoms between attacks; (3) absence of systemic reaction; and (4) absence of a specific etiological factor which would account for the articular symptoms, that is, bacteria, rheumatic fever, trauma, and purpura. The authors excluded from the series all patients with articular symptoms which recurred at irregular intervals, true periodicity not having developed. Forty-seven cases met the criteria and were considered representative of periodic benign synovitis (Table I).

CLINICAL MANIFESTATIONS AND TREATMENT IN FORTY-SEVEN CASES

Age and Sex

The age of the patient at the time of onset of periodic benign synovitis is variable,

TABLE II

CLINICAL MANIFESTATIONS IN THE JOINTS OF FORTY-SEVEN PATIENTS

	No. of Cases	Per Cent
Effusion	36	76
Pain	35	74
Limitation of motion	26	55
Effusion and decrease in motion but no pain	8	17
Calor, minimal	7	15
Pain and limitation of motion but no effusion	4	8
Rubor, minimal	3	6

TABLE III

SUBSEQUENT COURSE OF THE DISEASE IN THIRTY-SEVEN PATIENTS OBSERVED FOR TEN TO FORTY-SEVEN YEARS AFTER ONSET OF SYMPTOMS

	No. of Cases	Per Cent
Remission	20	54
Spontaneous	16	43
Following synovectomy of knee	6 knees	67 *
Attributed to roentgen therapy	1	3
Asymptomatic while taking medication	1	3
Clinically improved (milder attacks, longer intervals)	4	11
Disease still present	12	32

* Per cent of nine knees. Synovectomy was performed on only nine knees of seven patients. Six of these knees in four patients (67 per cent of the knees operated upon) have been asymptomatic since the operation. See also footnote†.

† In one case the left knee has been asymptomatic for fourteen years following synovectomy, but periodic benign synovitis has become manifest in the left elbow.

but the appearance of symptoms in a patient prior to puberty has not been reported in the literature or found in this series. In the authors' group, thirty-three patients were females and fourteen were males. The distribution as to age and sex is shown in Chart 1. The youngest patient at the time of onset was a thirteen-year-old girl; the oldest was a forty-five-year-old woman. In two girls the onset of articular symptoms coincided with the menarche.

Familial Occurrence

The disease rarely affects more than one member of a family. The sister of one of the authors' patients, in whom both knees were affected, was said to suffer from similar periodic attacks, and another patient thought that her mother had the same trouble in her knees. In neither of these cases was the presence of the disease fully authenticated.

Symptoms and Signs

The clinical manifestations are presented in Table II. Pain, limitation of motion, and swelling of the involved joint were the symptoms most often noted. Pain, which was found in thirty-five (74 per cent) of the patients, was frequently present only when the distention of the joint space was maximal and was often promptly relieved by aspiration of the fluid. The involved joint was never intensely hot or red. The pain was not fibrositic in nature, and the pain and stiffness were never worse after periods of inactivity or better after mild exercise. There were no instances of muscular aches, pains, and tenderness or of a general feeling of muscular weakness.

In this disease the attack may start suddenly or gradually. In most of the authors' cases the attacks lasted three, four, or five days; in some they lasted only twenty-four to forty-eight hours and in a few cases they lasted six or seven days. Only occasionally was the onset of an attack associated with trivial trauma, and there was no apparent relationship between the onset of an attack and the time of day.

Some joints were involved singly and others were involved coincidentally or alternately with other joints. In this series the knee was the joint most frequently involved and in thirty patients (64 per cent) involvement was limited to one or both knees. In four patients (8 per cent) the knees were never involved. In one of these four the hip was affected; in another the hip and the ankle were involved alternately; in a third only one ankle was affected; and in the fourth the hands and feet were affected simultaneously.

TABLE IV

INFLUENCE OF PREGNANCY, MENSES, AND MENOPAUSE ON PERIODIC BENIGN SYNOVITIS

	No. of Cases
Pregnancy:	
Remission	9
No remission	1
Menses:	
Attacks worse when coinciding with the menses	8
Attacks unchanged when coinciding with the menses	6
Onset with the menarche	2
Menopause:	
Gradual relief with cessation of attacks after the menopause	1
No relief	3

In the remaining thirteen patients (28 per cent) other joints, commonly the elbow, shoulder, jaw, hip, or ankle, were involved coincidentally or alternately with both knees.

In this study the authors considered the interval between attacks as being the length of time between the onset of one attack and the first day of the succeeding attack. In some cases this time interval remained constant throughout the course of the disease; in other cases it suddenly became shorter or longer. If the periodicity did change, the new interval then prevailed for months or years. For example, attacks may initially occur twenty-one days apart, but after months or years the interval may suddenly decrease to fourteen days. In one case there was initially alternate involvement of the knees every fourteen days, but eventually both knees became symptomatic every fourteen days. In another case, symptoms developed in the hips and left ankle every ten days during the twenty-eight years the patient was observed. In this series the most common interval between attacks was fourteen days; next in order of frequency were intervals of ten days and twenty-one days. Extreme limits of four and thirty days were noted. Several patients stated that disappearance of the attacks was preceded by a period of six months to a year during which the attacks no longer recurred at regular intervals but recurred farther and farther apart until they eventually disappeared.

The duration of periodic benign synovitis is unpredictable. One of the authors' patients with onset at the time of the menarche (Case 12) is still having attacks after the menopause at the age of sixty-one years. This patient's attacks have occurred over a span of forty-seven years with relief during pregnancy and remissions for two to three months after x-ray treatment. In other cases, apparently spontaneous remissions of one, two, or even five years have been followed by recurrence. A spontaneous remission, without known recurrence, lasting for fourteen years, was noted in a patient who had had symptoms for eight to ten months.

Thirty-seven patients have been observed for periods of ten to forty-seven years following the onset of periodic benign synovitis (Table III). Of this group, twenty (54 per cent) were no longer having periodic articular symptoms or any other form of musculoskeletal infirmity when they were last seen. Four patients (11 per cent) were having milder attacks with increasingly longer intervals of freedom between attacks. One patient felt that current medication was maintaining control of the disease by preventing attacks. Twelve patients (32 per cent) were continuing to have attacks at regular intervals, but in none of these patients was there any evidence of permanent crippling, articular deformity, or progression to rheumatoid arthritis. One patient reported that he was completely incapacitated for two to three days every two weeks and that he was therefore unable to hold a job. Another, who continued to have attacks in her knees despite unila-

TABLE V

EXAMINATION OF SYNOVIAL FLUID

Case	Total Protein (*Grams*)	Leukocyte Count (*Cubic Millimeters*)	Differential Count		
			Lymphocytes	Monocytes	Polymorphonuclear Neutrophils
1	5.0	1300	91	2	7
4	4.2	300	62	22	15
13					
(1952)		800	98	0	2
(1953)		3400	4	0	96
18					
(2–12–37)		500	99	0	1
(2–23–37)	4.9	3400	68.5	0	31.5
19	4.5				
21	4.8	6500	22	20	58
24	4.5	3000	35	64	1
28	4.8				
36	3.8	2900	55	38	7
41	4.3	3800	35	7	47

teral synovectomy, reported some stiffness in one thumb. That this might be an early manifestation of rheumatoid arthritis remains a possibility, but the symptoms were certainly not clear-cut at the time the patient was last seen.

The influence of menses, pregnancy, and menopause on periodic benign synovitis is noteworthy; details concerning this influence are given in Table IV. Nine women experienced remission during pregnancy, and only one woman stated that her attacks continued unabated. The relief which started during pregnancy generally persisted for three to four months following parturition. One patient experienced relief "even before I found out I was pregnant". Another stated, "If I could be pregnant all the time, I am certain I would be all right."

Laboratory Data

Patients with periodic articular disease have been reported to have normal leukocyte counts, normal sedimentation rates, and no anaemia. The validity of these reports, particularly with regard to the finding of normal hemoglobin and normal leukocyte and differential counts, has been borne out by the findings in the authors' cases. In thirty-seven of the forty-one cases in which the sedimentation rates were measured (Westergen method), the readings were less than twenty-five millimeters in one hour. In twenty-two of these thirty-seven cases the readings were made during an acute attack. In several other cases, isolated elevations were noted (Table I). Usually the sedimentation rate in a given patient was the same whether it was determined during an attack or during a symptom-free interval. There were no cases of peripheral eosinophilia.

Roentgenographic Findings

The roentgenographic findings were for the most part negative. The only exception was evidence of thickening of the synovial membrane which was occasionally found when the examination was made during the height of an attack. Six patients had minimal

TABLE V

EXAMINATION OF SYNOVIAL FLUID

(*Per Cent*) Basophils	Eosinophils	Sugar (*Milligrams per 100 Cubic Centimeters*)	Miscellaneous
0	0	75	Guinea pig negative.
1	0	109	pH 7.4; guinea pig negative.
0	0		
0	0		Bilirubin 0.4 milligram; *Nocardia asteroides* on culture; second culture negative.
0	0		Diphtheroids on culture.
0	0	70	pH 8.0; guinea pig negative; diphtheroids on culture.
			Specific gravity 1.031; albumin-globulin ratio 1.2:1; guinea pig negative.
0	0	78	Albumin-globulin ratio 1:1.4; pH 7.3; chloride 650 milligrams.
0	0	95	Albumin-globulin ratio 1:1; pH 7.2; guinea pig negative.
		50	Guinea pig negative.
0	0	83	Guinea pig negative.
0	11		Guinea pig negative.

hypertrophic changes. Most of these patients were elderly and had had the disease for a long time.

Synovial Membrane and Synovial Fluid

In ten cases the synovial fluid was examined; the findings of the examinations are summarized in Table V. The value for total protein ranged from 3.8 to five grams per 100 cubic centimeters, and the leukocyte count varied from 300 to 6,500 cells per cubic millimeter, the general range being between 300 and 4,000. The mononuclear elements were predominant in all but three of the specimens, and no specimens contained a large number of eosinophils. It is probable that the variations in the leukocyte and differential counts were reflections of the fact that the examinations were made during different stages of the attacks. Cultures for tuberculosis were negative. In one case *Nocardia asteroides* was cultured from the synovial fluid, while in another diphtheroids were recovered. In neither instance was the presence of the organisms considered to be related to the periodic benign synovitis. In no case was the level of uric acid or the brucellergen titer elevated.

Specimens of synovial membrane were obtained from the knees of ten patients by means of needle biopsy or surgical incision. Grossly, the synovial membrane usually appeared hyperaemic, thickened, and oedematous. In all of the patients villous formation was present, the villi varying from long, thin, shaggy projections to small, fine, almost imperceptible projections. Five patients who underwent synovectomy had thickened membranes with long, bushy, villous synovial projections indicating the presence, in severe cases at least, of permanent underlying synovitis.

Microscopically, the picture varied from that of subacute synovitis to chronic synovitis. In the cases in which the villi were not grossly apparent, they were readily apparent in microscopic sections. The villi in all cases were oedematous to a greater or lesser degree and were hyperaemic. The vessels in the villi appeared somewhat dilated and occasionally had thickened walls. In some cases the synovial membrane and villi

TABLE VI

RESULTS OF SURGICAL TREATMENT

Treatment	Total No. of Cases	Remissions (*Cases*) Complete	Temporary	None
Synovectomy of knees	7 (9 knees)	4 (6 knees)	3 (3 knees*)	0
Extraction of teeth	7	0	3	4
Tonsillectomy				
Alone	4	0	0	4
Combined with extraction of teeth	1	0	1	0
Miscellaneous				
Synovial biopsy	2	1	1	0
Patellar scraping	1	0	0	1
Transplantation of portion of quadriceps tendon into knee	1	1†	0	0
Meniscectomy	1	0	0	1

* One patient (Case 16) had a remission which lasted for seven months. He then had a recurrence of periodic benign synovitis in the knee which lasted for nine years. After this time the attacks ceased, and he has been free of attacks for the last twelve years.

† The immediate result was poor, but there was gradual cessation of attacks. At the time of the last follow-up complete remission had lasted for sixteen years.

were markedly infiltrated with plasma cells and lymphocytes, while in other cases the membrane was characterized more by oedema and hyperaemia than by cellular infiltration. The cellular infiltration was sometimes focal and confined to perivascular regions and other times was diffuse. The histological sections were reviewed by Dr. David C. Dahlin, of the Section of Surgical Pathology, who stated that the microscopic picture in all cases was compatible with, but not necessarily diagnostic of, rheumatoid arthritis.

Treatment

Many and varied types of treatment were employed in an effort to obtain relief for these patients. In no case was the attack suppressed by aspirin and in only a few did aspirin give any measure of relief. Physical therapy was likewise of benefit to only a few patients. Roentgen therapy was used in four of the patients, two of whom experienced no relief. One patient attributed cessation of his attacks to x-ray treatment, while another stated that she could anticipate a remission of two to three months when given two x-ray treatments, each consisting of 320 roentgens directed through a lateral and posterior field to the left hip.

ACTH, cortisone, or hydrocortisone was given to six patients with variable effects. One patient received cortisone in such quantities that hypercortisonism was produced, with no effect on the periodic benign synovitis. Another patient received twenty-four intra-articular injections of hydrocortisone in two years with only occasional benefit. A woman who received twenty milligrams of hydrocortisone intramuscularly daily believed her attacks of periodic benign synovitis were milder as long as the treatment was continued.

Many other medicaments and hormones were prescribed, including diethylstilbestrol, ergotamine, vitamin D, estrone, sodium cacodylate, gold, and antihistiminics. Another method tried was desensitization to histamine; and autogenous vaccines, typhoid vaccines, and foreign-protein vaccines were also employed. In almost every case these methods were ineffectual. One patient experienced a twelve-year remission while taking 50,000 units of vitamin D daily, and three patients experienced elimination of an attack

or two while undergoing desensitization to histamine. Often a medicament that would seem to abort or prevent one attack would have no effect on a subsequent attack in the same patient. This suggests that the apparent improvements which were obtained may have been mere coincidences.

Surgical Procedures

Because of attacks of unusual severity, synovectomy was performed on nine knees in seven patients. Four of these patients experienced no further attacks in the knees treated by synovectomy, but the other three patients (Cases 13, 16, and 44) had recurrences, two in seven months and the third two years after operation. In one of the former, the recurrent attacks lasted nine years; then spontaneous remission occurred. This remission has lasted to date, a period of twelve years.

Details concerning the four patients (Cases 5, 15, 17, and 23) who experienced complete remissions in the knees treated by synovectomy are as follows: One patient upon whom synovectomy of both knees was performed has been free of symptoms for the last twenty-eight years and another upon whom synovectomy of the right knee was performed has had complete remission for the last nineteen years. In one patient (Case 17) a remission of symptoms which has lasted seventeen years was obtained by synovectomy in the right knee, but later the left knee became affected. Synovectomy of this knee resulted in a complete remission which has lasted to the present, a period of thirteen years. The fourth patient has been free of attacks in the left knee for the fourteen years which have elapsed since synovectomy, but an elbow and ankle have become affected (Table III).

Other surgical procedures, such as tonsillectomy, extraction of teeth, and adenoidectomy, were done to remove foci of chronic infection but were without favorable effect. The results following synovectomy of the knee and other surgical procedures are summarized in Table VI.

CASE HISTORIES

Case 12. A housewife, thirty-eight years old, came to the Clinic in 1933, with complaints of intermittent pain and limitation of motion in her left hip of twenty-four years' duration. The initial attack had occurred with no known provocation when the patient was fourteen years old and had been preceded by twenty-four to forty-eight hours of low-back pain which had disappeared with the onset of the pain in the hip. Each attack experienced by this patient followed the same course. By two to four days after the onset of pain in the hip, the patient would be completely asymptomatic and would remain asymptomatic for the next six to eight days, until the next attack commenced ten days after the onset of the previous attack. Early in the course of the disease, symptoms had been manifest in either or both hips, but after a few years the prodromal backache and involvement of the right hip had disappeared. During the attacks, aspirin and local heat afforded some relief.

Physical examination, laboratory tests, and roentgenograms made in 1933 disclosed normal conditions. A diagnosis of migraine equivalent was considered, and the patient was dismissed with no specific therapy.

In 1951, the patient returned to the Clinic. The attacks of pain in the left hip had continued to recur at intervals of ten days. The attacks were of the same duration as they were when the patient was seen in 1933, but they were perhaps more severe. Occasionally during the first day or two of the attack, the patient would be confined to bed because of intense discomfort. Since 1933, the attacks have occurred regularly except during pregnancy and the three months after parturition. Coincidence of the attacks with menses did not appear to alter the symptoms or prolong the attack. The findings of the physical examination and laboratory tests were again within normal limits. Roentgenograms revealed minimal osteo-arthritic changes in both hips, perhaps more on the left side than on the right.

Physical examination in 1954 revealed that there was slight atrophy in the left thigh, but that motion of the left hip was within normal limits. The sedimentation rate was sixteen millimeters in one hour and the concentration of hemoglobin and the leukocyte count were normal. Roentgenograms of the hips and pelvis showed that conditions had not changed since 1951. In the previous few years the patient had received female sex hormones, calcium gluconate, and phenylbutazone but had obtained no relief. Her attacks were slightly more severe than they had been early in the course of the disease, and she was forced more frequently to go to bed at the height of an attack. Attacks were sufficiently bothersome for her to alter plans for trips,

entertainment, and vacations. She said, "Even though during an attack I cannot bend my hip sufficiently to permit me to tie my shoe, I am completely well once the attack is over." Roentgen therapy resulted in a remission of three months and two repetitions of x-ray treatment were each followed by a remission of two months.

The patient was last seen in June 1955. She was sixty-one years old and had been through menopause but was still having the attacks in the left hip at ten-day intervals, forty-seven years after the first episode.

CASE 14. This white woman, thirty years old, came to the Clinic in 1934, because of intermittent episodes of pain in the left knee. The first episode of articular pain that she had experienced had occurred six years previously and had consisted of pain in the right shoulder. At first the pain in the shoulder had recurred at rather irregular intervals, occasionally alternating with episodes of pain in the left knee. Six months after onset, however, regularity had become apparent and the shoulder would become involved every ten days. The episodes of shoulder pain still occasionally alternated with episodes of pain and swelling in the left knee. The attacks in the shoulder were worse in cold weather; those in the knee were worse in warmer weather. Four years after onset, the shoulder episodes had disappeared and thereafter the left knee alone had bothered her.

The attacks in the knee lasted for three or four days and occurred at ten-day intervals. When the attacks coincided with her menses, the pain and swelling were much more severe. The patient experienced relief throughout pregnancy.

Physical examination made during the height of an attack revealed a painfully swollen knee with effusion but with no limitation of motion. The knee showed neither redness nor increased warmth. The value for hemoglobin was fourteen grams per 100 cubic centimeters, and the sedimentation rate during the attack was twenty-five millimeters in one hour. Roentgenograms of the knees and shoulders were negative. At this time a diagnosis of atypical rheumatoid arthritis involving the knees and shoulder was made. Treatment consisted in the administration of sodium cacodylate and typhoid vaccine, but the patient obtained no relief.

The patient was seen again in 1941. She was still having regular recurrent episodes of periodic benign synovitis in the left knee joint, but with no increase in the severity or duration of the attacks. The findings of laboratory tests and of roentgenograms of the shoulder and knee were essentially the same as those obtained seven years earlier. During an attack the sedimentation rate was twenty millimeters in one hour. The use of symptomatic measures during attacks was recommended and the patient was dismissed.

In 1955, the patient wrote that she had been free of attacks for the past twelve years. She had no other disability related to her bones or joints and was unable to explain the spontaneous remission which had occurred fifteen years after her first attack.

CASE 15. This white man, thirty-two years old, came to the Clinic in December 1935. Painful accumulations of fluid in the right knee joint had been occurring at regular intervals of twenty-one days for the past two years. The pain, swelling, and limitation of motion in the knee would last for five, six, or seven days. Between attacks the patient felt well and his knee seemed normal. No other joint was involved.

Physical examination made during an attack revealed that the right knee was severely painful and swollen with ballotable fluid. Motion was limited because of pain, but neither redness nor increased warmth was noted. The remainder of the musculoskeletal system was normal. The leukocyte count was 13,000 cells per cubic millimeter and the value for hemoglobin was 13.5 grams per 100 cubic centimeters. A roentgenogram of the right knee showed no abnormality.

Because of the intense pain and disability which were present during each attack, synovectomy was performed on the right knee in January 1936. The synovial membrane was oedematous and hyperaemic, and there were long thin villi. Microscopic examination revealed that the synovial membrane at the margin of the joint was covered with long slender branching villi. There was more oedema in the subsynovial layer than in the villi, but the moderate infiltration of mononuclear cells, which was diffuse, seemed to be more apparent in the villi. The cellular infiltrate showed no predilection for perivascular areas. In general the picture was that of chronic synovitis (Fig. 1).

The patient was seen again in 1937. The knee that had been operated on was slightly stiff but no further attacks of effusion or pain had occurred. The sedimentation rate was eleven millimeters in one hour. When the patient was re-examined in 1945, his right knee had a normal range of motion and was free of pain, but he reported that transient episodes of pain had been occurring at irregular intervals in the left knee. This knee appeared normal. The sedimentation rate was ten millimeters in one hour. Whether or not periodic benign synovitis would develop in this knee was not known.

The patient wrote in 1955 that the disability in his right knee had not recurred since synovectomy in 1936 and that he had had no further trouble with his left knee since the examination in 1945.

CASE 17. When this white man, twenty-seven years old, came to the Clinic in 1935, swelling in the right knee had been recurring regularly at fourteen-day intervals for eight years. This swelling would be

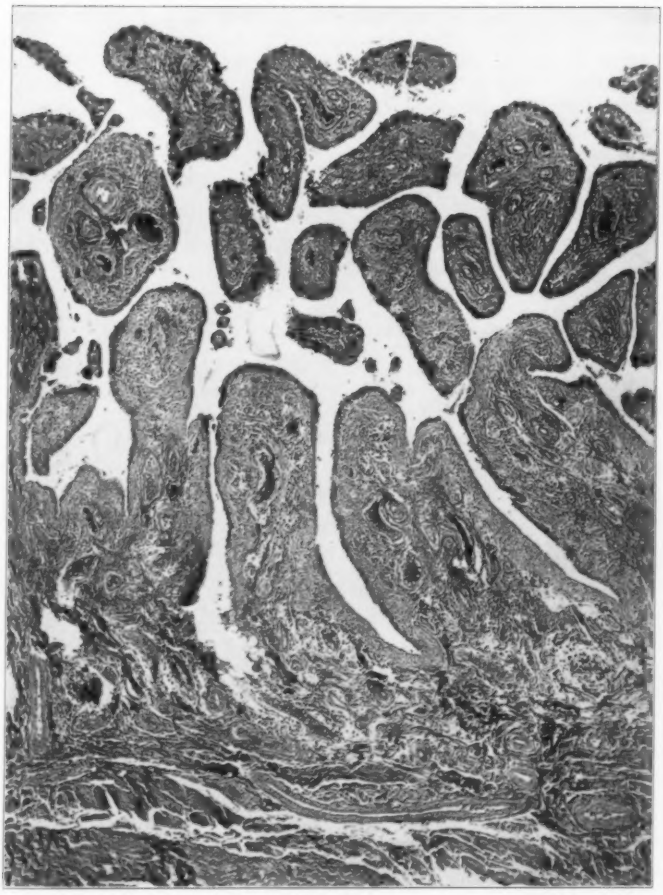

FIG. 1

Case 15. Photomicrograph of synovial membrane, showing the long branching villi. Moderate vascularity and diffuse infiltration of mononuclear cells are apparent (hematoxylin and eosin stain; × 80).

present for five or six days and then would subside. Early in the course of the disease there had been no marked discomfort or limitation of motion, but during the previous two years the attacks had been much more painful and bothersome.

On physical examination the right knee was found to be painful, swollen, and slightly tender. There was slight limitation of motion but there was no redness or increased warmth in the joint despite the fact that effusion was present. The findings of the remainder of the physical examination, of routine laboratory tests, and of roentgenograms of the knee were within normal limits. Because the attacks were not incapacitating, operation was not considered. Treatment consisting of analgesics for symptomatic relief was recommended, and the patient was dismissed.

The patient returned in 1938 because the attacks were becoming much more painful and were interfering with his activities. Synovectomy was performed on the right knee. Grossly the synovial membrane appeared thickened and hyperaemic with villous proliferation. Microscopic examination showed that the villi were long and broad and that the lining membrane was thickened. The villi were filled with a large amount of fat and a moderate amount of fluid. There was marked infiltration of plasma cells and lymphocytes, particularly about the periphery of each villus. Some focal collections of cells were found deeper in the villi; in some instances these were perivascular and in others they were not (Fig. 2).

The patient was seen again in 1943. His right knee was free of attacks, but periodic benign synovitis was occurring every fourteen days in the left knee and occasionally attacks in the left elbow were coincidental.

Physical examination during an attack revealed a painful swollen left knee with effusion and slight limitation of motion. There was no rubor or calor. On examination the left elbow appeared normal. Roentgenograms of the left elbow and left knee and laboratory tests gave negative results. The sedimentation rate during the height of an attack was eleven millimeters in one hour. The patient was initially treated by roentgen therapy, but when this proved ineffective, synovectomy of the left knee was performed. The gross and microscopic appearance of the synovial membrane in this knee was similar to that of the membrane obtained at synovectomy from the right knee four years earlier.

The patient wrote in 1955 that he had "some fluid in the bursa below the knee joints" but that he had no pain or limitation of motion in either knee.

Case 41. This man, thirty-eight years old, came to the Clinic in November 1947, because of the occurrence of swelling and limitation of motion in the right knee during the preceding ten years. The first episode of articular swelling had occurred four months after he had contracted gonorrhea. The initial treatment had consisted in aspiration of the synovial fluid, and the patient had had no further distress for one year, after which time intermittent swelling of the knee began. The attacks in the knee lasted for two to three days and occurred about twenty-one days apart. For the past six months swelling and limitation of motion had developed in the right knee every ten days to the day. The patient could prophesy the time of onset within eight or twelve hours. Recently the attacks had lasted four to five days. After each episode the patient felt completely well.

Fig. 2

Case 17. Photomicrograph showing a broad villus with a thickened layer of lining cells. Deposits of fat and marked cellular infiltration about the periphery of the villus are apparent (hematoxylin and eosin stain; × 50).

Examination of the right knee revealed the presence of free fluid and some thickening of the synovial membrane. There was slight loss of motion in the joint but no redness, increased warmth, or tenderness. No other joint was involved.

The value for hemoglobin was fourteen grams per 100 cubic centimeters, and the sedimentation rate, measured during the middle of an attack, was eleven millimeters in one hour. The findings of roentgenograms of the right knee were negative. The aspirated synovial fluid contained 3,800 leukocytes per cubic millimeter. Forty-two per cent of these cells were mononuclear cells, 47 per cent were polymorphonuclear neutrophils, and 11 per cent were eosinophils.

In December 1947, open biopsy of the synovial membrane of the right knee was done. At arthrotomy the membrane was removed from the synovial reflection of the medial femoral condyle, and further representative samples were taken. No pannus was found. Grossly, the synovial membrane appeared markedly hyperaemic and slightly thickened. Large thick villi were present. Microscopic examination revealed that the many short stubby villi were vascular and that much of the plasma-cell and lymphocytic infiltrate was perivascular. The lining layer of the synovial membrane was only slightly thickened and the subsynovial layer was moderately oedematous (Fig. 3).

When the patient returned to the Clinic in 1950, because of an unrelated condition, examination of his knee revealed no abnormality, and the sedimentation rate was five millimeters in one hour. He had experienced no further attacks of periodic benign synovitis since the synovial biopsy. Correspondence from the patient in 1955 indicated that his apparently spontaneous remission was still continuing, eight years after his last attack.

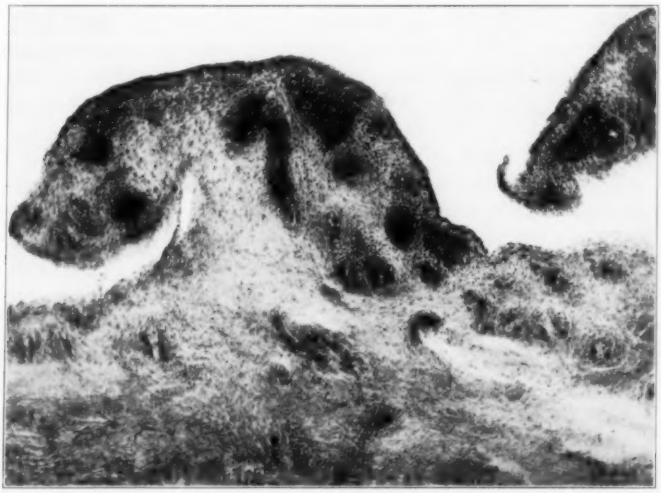

FIG. 3

Case 41. Photomicrograph showing perivascular accumulation of plasma cells and lymphocytes in a moderately oedematous villus (hematoxylin and eosin stain; × 50).

PATHOGENESIS

The pathogenesis of periodic benign synovitis is not clear. In 1888 Fridenberg stated that the condition was a rare form of vasomotor neurosis. He wrote that disturbance of the vasomotor nerve cells in the wall of a blood vessel could cause local changes in tension and sequelant capillary exudation, resulting ultimately in the formation of local hydrarthrosis. Since 1888 many causative factors have been considered, including trauma, brucellosis, rheumatic fever, rheumatoid arthritis, allergy to food, and endocrinal abnormalities. Some relationship to hormonal function has been inferred because of the frequent remissions encountered during pregnancy as well as because of the association of the disease with menses, as noted earlier. Recent studies in which Shorr stain was used have demonstrated that estrogenic regression sometimes occurs in women with intermittent hydrarthrosis.[18]

Several authors have reported cases of intermittent hydrops in patients who have allergic manifestations[1,10,17]. In the authors' series, one patient (Case 24) who had been having attacks in the right knee every ten days for one year ate no fish throughout her vacation and during this time noted a remission. This patient also noted that eating iodized salt during an attack would intensify the attack. The removal of both fish and iodized salt from her diet resulted in a remission of more than two months, the longest period of freedom from attacks which she had experienced. Unfortunately, further information concerning this patient's course has not been available to the authors.

Most of the women in the authors' series experienced relief during pregnancy and about half of those reporting believed the attacks were worse when they coincided with the menses.

It has been maintained that there are two forms of periodic synovitis: a true idio-

pathic variety in which no causative agent is ever found and so-called symptomatic intermittent hydrarthrosis which develops in association with a chronic disease such as rheumatoid arthritis[6,9,12]. As mentioned previously, none of our patients later manifested chronic arthritis or any other deforming articular disease.

Seifter, Baeder, Begany, in their studies on rabbits, collected data supporting the concept that ACTH, cortisone, and estrone decrease synovial permeability, whereas desoxycorticosterone acetate increases it. Sympathectomy also decreases capillary permeability[3]. One interesting speculation is that a delicate reciprocal relationship exists between hormones and that when this relationship is upset, a cyclic reaction may be produced in any joint that is already predisposed by vasomotor lability to pathological reactivity. Another view which is held by one of the authors (R. K. G.) is that these intermittent, apparently benign attacks may represent an underlying rheumatoid state which never really becomes established and which ultimately burns itself out before permanently disabling the joint.

DIAGNOSIS

Diagnostic Criteria

In the authors' opinion the features which must be present if a diagnosis of this syndrome is to be made are the four conditions which were used as a basis for selecting the cases described in this study, namely: (1) cyclic recurrence of attacks at regular intervals; (2) complete freedom from symptoms and signs between attacks; (3) absence of a specific local causative factor; and (4) absence of systemic reaction. Periodic benign synovitis recurs with a rhythmicity that defies explanation. Unfortunately for diagnostic purposes, a patient may experience many attacks of articular symptoms before the rhythmicity becomes established. Once the periodicity does become established, many more attacks may occur before the patient becomes aware of the peculiar time relationship of his attacks. For this reason, when the diagnosis of periodic benign synovitis is suspected, the patient should be requested to record his attacks on a calendar. Often the diagnosis is deferred for many months because the time relationship has been obscured as a result of the forgetfulness of the patient. In other instances the attacks of pain may be so mild that the patient accepts them, particularly if they are of brief duration, and he does not seek a doctor's advice until months or years after onset.

The interval between attacks remains the same for a long time once periodicity becomes established. Many patients are forced to plan their activities so that they will coincide with periods of anticipated well-being. Ragan mentioned the athletic schedule of a university which was supposedly arranged so that matches would come at a time when the star athlete, who had periodic benign synovitis, anticipated a remission. The interval may not remain constant throughout the entire course of the disease, however; for example, attacks which now come every fourteen days may, at some future date, recur every twenty days. Once the pattern has changed, however, the attacks will recur regularly for another prolonged period.

If complete normalcy is not established in the joint between attacks, the diagnosis of periodic benign synovitis should be excluded. This diagnosis is also untenable if the joint exhibits what appears to be periodic exacerbations but remains chronically involved for long periods.

Clinical Findings

Involvement of more than one joint should not exclude the diagnosis of periodic benign synovitis. In several of the authors' cases more than one joint was involved at onset, but in most cases only one or occasionally two joints continued to be involved. In no instance did symptoms migrate from joint to joint during a single attack. Although the knee was the joint most commonly affected in the authors' group (forty-three of the

forty-seven cases), this disease is not peculiar to the knee. Involvement of the hip alone or in combination was present in four of the authors' forty-seven cases, a fact which demonstrates that the incidence of involvement of a hip is higher than is generally recognized. The previous reports of a low incidence in the hip may be a reflection of the difficulty of recognizing the presence of fluid in the hip. In the authors' cases attention was drawn to the hip because of pain and limitation of motion. Fluid alone would have almost certainly passed unnoticed and the involvement of the hip would not have been detected until enough fluid had accumulated to cause pain; hence, the incidence of involvement of the hip may be even higher than that found in the authors' series.

Findings of the Laboratory Tests and Roentgenograms

Hematological studies and roentgenograms are valuable in establishing the diagnosis only in that they may be used to rule out the presence of other specific maladies. The variability in the differential counts obtained for the synovial fluid in the authors' series is probably a reflection of the fact that the counts were made during different stages of the attacks, for it is known that the polymorphonuclear cells predominate early in the attack, while later, as the attack subsides, the percentage of polymorphonuclear cells generally decreases and that of mononuclear cells increases[15]. This was demonstrated in the three cases in which synovial fluid was aspirated at the termination of an attack. In these cases the total cell counts were less than 800 cells per cubic millimeter and the percentage of mononuclear elements was 99, 98, and 84 respectively.

One report in the literature indicates that in patients with periodic benign synovitis the synovial fluid accumulates without there being any changes in the mucopolysaccharides (hyaluronic acid)[11]. This has been considered evidence that the fluid is a simple transudate in which there has not occurred the change in the metabolism of hyaluronic acid that is found in the synovial fluid of patients with rheumatoid arthritis. However, to presume that the synovial fluid is the result of simple transudation leaves unexplained the cellular accumulation and the change in differential cell count which occurs during the different stages of the attack.

Pathological Aspects

As has been mentioned, several of the specimens obtained by means of synovectomy of the knee joint were characterized by the presence of long, bushy, villous projections. The presence of these projections indicates that, in severe cases at least, there may be a permanent underlying synovitis. The fact that the attacks are periodic with completely asymptomatic intervals does not rule out this possibility.

The histological picture of the synovial membrane in patients with this condition is compatible with that seen in patients with rheumatoid synovitis. By those subscribing to the belief that this microscopic picture is pathognomonic, periodic benign synovitis is generally classified as a rare form of rheumatoid synovitis which does not lead to pannus formation, destruction of cartilage, and eventual ankylosis with articular deformity. Others, however, may judge that the microscopic picture is non-specific and consider periodic benign synovitis as an entity apart from rheumatoid synovitis.

TREATMENT

Treatment of patients with periodic benign synovitis has not been highly successful. Many and sundry agents have been tried without success. One patient stated that she spent $1,200 in a period of less than three years for medication alone and that none of this medication relieved or aborted an attack of articular pain. The occurrence of spontaneous remissions makes evaluation of surgical and other forms of therapy particularly difficult. No form of medical therapy has been reported in a published series as being completely efficacious over a prolonged period.

In patients with severe involvement of the knee joint the best results appear to follow synovectomy, but even this form of treatment is not completely successful. In this series complete relief followed synovectomy in six of the nine knees operated upon; recurrence developed in the other three knees from seven months to two years after operation. An excised synovial membrane may be replaced by either regeneration or metaplasia [1,8], and it is probable that the new synovial lining can become involved in this peculiar disease process.

A more extensive trial of x-ray treatment seems to be warranted, for studies of synovial membranes treated by irradiation reveal disappearance of oedema, increase in fibrosis, thickening of the vessel walls, and obliteration of the smaller vascular channels in the subsynovial tissue[7]. In the authors' series, however, only two of the four patients treated by radiation experienced relief.

Sympathectomy is believed to alter capillary permeability. The effect of autonomic block and its influence upon the hyperaemic synovial membrane is not known, but it is interesting to speculate whether the decreased permeability brought about by surgical or non-surgical sympathectomy might prevent the accumulation of fluid in patients with periodic benign synovitis. No reports concerning the results of this mode of therapy have been found.

Spontaneous remissions unrelated to any form of treatment occur in this disease and in some cases such remissions have persisted throughout the remaining period of observation. In other cases remissions of four and five years have been followed by recurrence of the disease.

Perhaps the best treatment for patients not severely afflicted is encouragement to live with this disease, with a more phlegmatic outlook. Complete freedom from attacks without residual deformity can be expected in approximately half of the cases.

SUMMARY

Periodic benign synovitis is characterized by the regular cyclic recurrence of articular pain, swelling, or limitation of motion without permanent deformity of the joint or injury to the bone. Forty-seven cases of this condition encountered at the Mayo Clinic were studied.

The criteria used in selecting these cases were: (1) recurrence of joint symptoms at regular intervals; (2) complete freedom from signs and symptoms between attacks; (3) absence of a specific local causative factor; and (4) absence of systemic reaction. Although the knee is the joint most frequently involved with periodic benign synovitis, any peripheral joint may be involved.

The microscopic picture of the synovial membrane obtained in cases of periodic benign synovitis is similar to that seen in cases of rheumatoid synovitis. Many who consider this microscopic picture as pathognomonic of rheumatoid arthritis may conclude that periodic benign synovitis is a rare form of rheumatoid synovitis; those who consider that this histological reaction is non-specific may favor the concept that periodic benign synovitis is a separate and distinct entity.

Spontaneous remissions are frequent, and results of medical and surgical treatment are particularly difficult to evaluate. Thus far no medical therapy has been found consistently effective. Synovectomy appears to be efficacious in cases of severely afflicted knee joints.

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DISCUSSION

Recurrent Ulnar-Nerve Dislocation at the Elbow

(*Continued from page 984*)

my study are accurate. It should be pointed out, however, that I found only 4 per cent of the elbows with complete dislocation; the remaining 12 per cent were hypermobile, with subluxation.

Dr. Obletz believes that an abnormal angle of the medial humeral epicondyle could explain this dislocation. It might well be a factor, although I noted no such bone abnormalities in the sixteen roentgenograms which I made of elbows with hypermobile nerves. The causation must be congenital because I have seen two infants, only a few minutes old, with bilateral ulnar-nerve dislocations. It seems probable that a congenital "loose anchorage" is the cause of such nerve dislocation.

Available for demonstration are my own two elbows. The nerve of the left elbow is Type A with incomplete dislocation, and the nerve at the right is Type B with complete displacement. Over a period of forty-eight years the left nerve has been subjected to direct trauma many times but the elusive right nerve has never been injured. I offer these personal facts as additional data for some of the conclusions made in this paper.

The Effects of Pressure on Epiphyseal Growth

The Mechanism of Plasticity of Growing Bone *

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"As the twig is bent the tree's inclined. . . ." Pope

That growing bone is plastic in the sense that its growth may be controlled by pressure has been known for centuries. Various bone deformities produced by artificial means, such as the elongated skulls of the ancient Egyptians and of certain American Indian tribes and the familiar Chinese bound-foot deformities, attest to this quality of bone. Other indications of the plasticity of growing bone can be seen in the practice of nose-flattening found among the South American Indians and among the natives of Sumatra and Polynesia, in the development of bow legs in natives accustomed to riding bareback, and in the development of bent legs and various deformities of the feet in the canoe people of Tierra del Fuego [11]. In ancient Rome "some persons even exercised the cruel art of stopping the growth of children by confining them in chests, or binding them with bandages, in order to prepare them for sale to the wealthy patrons of such stunted curiosities" [18]. An indication of the widespread use of these practices is the fact that the Latin words *nanus* and *pumilo* were terms commonly used to describe the natural and artificial dwarf [8].

Modern orthopaedic surgery is generally considered to have begun with Andry, whose familiar picture of the crooked tree bound to the straight rod symbolizes the plasticity of the structure of the growing child and illustrates the similar property of growing vegetable tissue **. A large proportion of the achievements of orthopaedic surgery depends upon this property of growing bone. The gradual non-operative correction of most bony deformities of childhood, such as bow-leg and club-foot, is obtained by the intelligent application of pressure in order to mold the shape of the growing skeleton.

The dictionary defines *plastic* as "capable of being molded . . . pliable, impressionable". In this sense, "plasticity" of bone exists only in time. At any one moment, bone, being a crystalline structure, is elastic rather than plastic and cannot be deformed by pressure as can a lump of clay. Bone can only grow into deformed shapes if pressure is applied more or less continuously during the period of growth. Hence, this discussion is specifically limited to conditions in the normal, living, growing skeleton; it will deal with the manner in which a plastic response is produced by the action of pressure on growing bone.

Growth in Length versus Growth in Thickness

With certain well recognized exceptions (bones which are laid down in fibrous tissue), all skeletal growth in length is, first of all, *cartilaginous*. This growth may occur in the epiphyseal plate, in the cartilaginous articular surfaces at the bone ends, at the apophysis, in the vertebral ring, or in (to use Bick's excellent term) the vertebral diaphyseal growth plate. Whatever the site, the increased length is added by multiplication of cartilage cells, these cells being later converted into bone by enchondral ossification.

* Read before the Orthopaedic Section of the New York Academy of Medicine, New York, N. Y., May 15, 1953.

** Prof. J. H. Taylor, of the Department of Botany at Columbia, has kindly pointed out some facts which indicate that Pope was more accurate, from a botanical standpoint, than Andry. The woody center of a tree of any thickness is dead and not plastic; hence, it cannot be molded by pressure as indicated in Andry's drawing. On the other hand, a twig can be held in any desired position until sufficient circumferential appositional growth is laid down to maintain the new position.

Growth in thickness, on the other hand, always occurs by the addition of new bone tissue to free bone surfaces, a process which Weinmann and Sicher call "appositional bone growth". Each trabecula of bone hypertrophies by the addition of new bone laid upon the old, and each atrophies by absorption of bone from the surface. The aggregate of these changes determines whether the bone as a whole is porotic or sclerotic. There are also changes produced by the periosteum and endosteum, which lay down or absorb new bone in layers parallel to the bone shaft [17].

Pressure has a different effect on each of these two types of bone growth, as can be demonstrated by histological sections (Fig. 8). Pressure stimulates appositional bone growth, as is expressed in Wolff's law. Thus, increased weight-bearing will result in increased thickness and density of the shaft of the tibia, a response which makes the bone better able to resist the stress which causes the response. The application of repeated angular stresses will be followed by hypertrophy of those trabecular systems which best resist such stresses. Under repeated stresses of this type, a normal bone will thicken but will never bend. Any bending which does take place will occur at the ends, where epiphyseal-bone growth occurs; the shaft itself will yield only if some pathological process such as Paget's disease or osteomalacia is present.

This does not mean that the shaft contours are never remodeled. Bones with healed angulated fractures or with other bowings of the shaft do tend to straighten, this straightening being produced by increased deposition of appositional periosteal bone along the concavity, where the most pressure falls. But this is not a manifestation of plasticity; just the opposite. If the shaft were plastic, it would angulate further with weight-bearing, whereas it actually straightens. Appositional bone growth does not yield to pressure. On the contrary, pressure stimulates the growth of just such appositional new bone as will best resist it.

Epiphyseal growth, on the other hand, yields to pressure, and this behavior is the principal mechanism in the plastic response of bone. Pressures as applied to the epiphysis, can be classified into one of two main types—those parallel to the direction of epiphyseal growth and those at right angles to this direction. Any force or group of forces applied in any direction intermediate between these two can be resolved into components, or vectors, parallel to one or the other. This paper will attempt to elucidate and systematize the behavior of the growth cartilage in response to these two types of stresses, each of which will be considered separately in the remaining portion of this paper.

THE EFFECT OF PRESSURES PARALLEL TO THE DIRECTION OF EPIPHYSEAL GROWTH

Review of the Literature

Pressures parallel to the axis of epiphyseal growth affect the rate of such growth. Increased pressure in this direction will inhibit growth; decreased pressure will favor and accelerate it. This relationship was recognized by Hueter and Volkmann in 1862; in the American literature it has been called the Hueter-Volkmann law. The first person to recognize this relationship, however, was Delpech, who, in 1829, described the case of a young girl with varus deformity of the ankle accompanied by obliquity of the inferior articular surface of the tibia. He ascribed this condition to inhibition of the growth of the tibial apophysis by pressure. "A strong dressing having been used with great diligence, and mutual contact of the deformed areas, in that manner, having been carefully prevented, at the end of sixteen months, . . . the articular surface had lost its vicious inclination, and the apophysis had grown, and the restoration of the foot was complete and strong: so that the leg which had been shorter, had recovered part of its natural length" [7]. Thus, not only did Delpech recognize the inhibitory effect of pressure upon epiphyseal growth and the stimulating effect of release of pressure — he even put his knowledge of this relationship to practical use! Hence Delpech's law rather than the

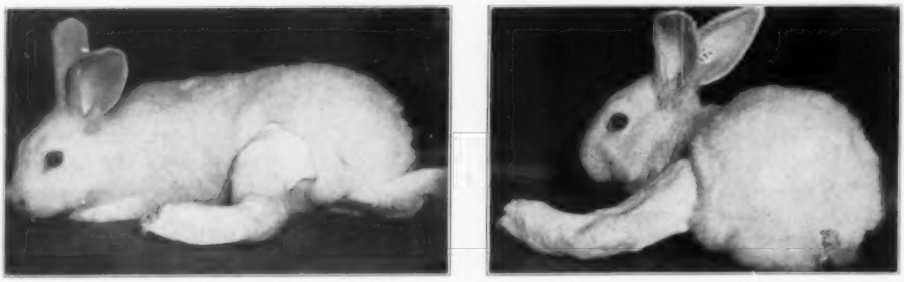

FIG. 1

Type of plaster cast used in the experiment to deviate the upper end of the tibia into a valgus position (rabbit no. 834).

Hueter-Volkmann law would seem to be the term of choice to describe pressure inhibition of epiphyseal growth.

More recently, valuable contributions have been made by investigators who have done experimental work on animals which confirms the findings of Delpech, Hueter, and Volkmann. Haas showed that compression by means of a wire loop would arrest epiphyseal growth and that growth would resume if the knot were untied. Blount and Clarke reported that similar results were obtained with metallic staples. These are now in extensive use clinically for correction of inequalities in leg length and for correction of angular deformities such as knock-knee. Quantitative estimates of the magnitude of the pressures necessary to stop epiphyseal growth have been given by Blount and Zeier. They found that the forces of growth in a child can break staples which are able to withstand 900 pounds of distraction in tests. Strobino, French, and Colonna published a study in which

FIG. 2

FIG. 3

Fig. 2: Roentgenogram, made twenty days after the start of the experiment, showing the appearance of the tibia in plaster. Some valgus deformity is already noticeable at the upper end of the tibia. There is no evidence of bending in the mid-shaft despite the fact that pressure was exerted on this region by the plaster.

Fig. 3: Femora and tibiae of rabbit no. 834 showing the valgus deformity which had developed after three weeks in plaster casts. A section of the upper end of the deformed tibia of this rabbit is shown in Fig. 7 and a photograph of both tibiae is shown in Fig. 22.

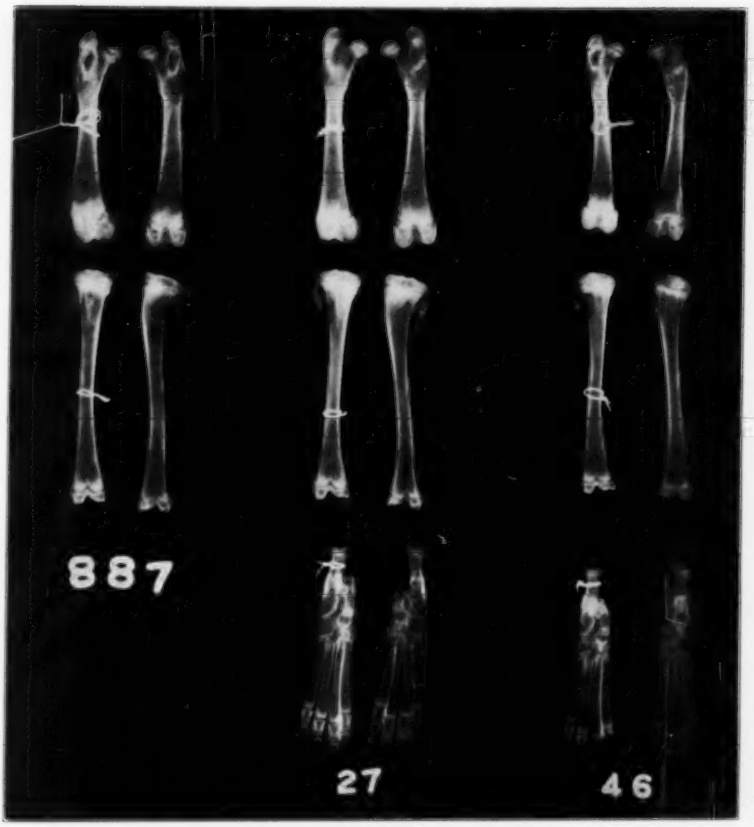

FIG. 4

Femora, tibiae, and foot bones of rabbits showing the valgus deformities which developed following three weeks in plaster. The right (control) bone is marked by a wire.

the forces of growth in a calf were measured by springs. They found that no inhibition of growth in the upper tibial epiphysis was caused by forces of up to 400 pounds. On the other hand, Appleton published an interesting and important article in 1934, in which he described the effects of relatively small forces upon the growth of bone in young rabbits. His experiments differed from those of the preceding authors in that the abnormal pressures applied to the rabbits' bones were the result of postural aberrations produced by surgical division of certain muscle groups. These were relatively mild pressures, comparable to those observed in children with paralytic poliomyelitis for example, and yet they resulted in the development of definite deformities which increased as the animals grew.

The results obtained by Appleton on the one hand and by Blount and his associates on the other are not mutually irreconcilable. Blount and his associates were talking about the force necessary to *stop* growth, for the wire or the staple does stop growth unless it breaks, while Appleton was discussing forces which only *slow* or *retard* growth. He wrote, "Increase of pressure within the limits attained in this experiment is sufficient to hinder growth in length of a metaphysis in the direction of pressure."

The experimental work outlined in this paper is intended to demonstrate that growth inhibition by pressures applied parallel to the axis of growth is not an "all-or-none" effect, but that minor degrees of pressure can slow growth without stopping it entirely.

FIG. 5

Fig. 5: Roentgenogram showing the deformities which developed in the left hind leg of a rabbit following six weeks in plaster casts. The small insert was cut from a roentgenogram of the same rabbit, made just before the initiation of the experiment. The roentgenographic technique and hence the scale was the same for both roentgenograms. All of the curvature produced by the plasters occurred in the new growth of bone and was due to a differential in the rate of growth. The shape of the portion of the diaphysis which formed the original shaft has not changed.

Experimental and clinical evidence will be offered to indicate that even gravitational pressures are sufficient to affect epiphyseal growth. Finally, there will be some discussion of the mechanism by which angular and torsional deformities are produced, for an understanding of this mechanism is important to an understanding of bone plasticity.

Experimental Work

The experimental animals used in this project were young rabbits, obtained as soon as possible after weaning. The average age was six to eight weeks. In each animal pressure was applied to the growing epiphysis by means of a plaster cast which held the left hind leg in the desired attitude of deformity. The cast was wedged or changed at weekly intervals, the abnormality of the position of the leg being increased with each succeeding change. The opposite hind leg was left untouched, as a control. Roentgenograms were made of each animal at the beginning of the experiment and at intervals during its course in order that the development of the deformity might be followed. One rabbit was discarded when a roentgenogram revealed a fracture through the lower femoral epiphysis. One other rabbit died from intercurrent disease. The fifteen remaining rabbits were followed to termination, and all are included in this report. At the conclusion of the experiment the animals were sacrificed, the bones of both hind legs were excised, and final roentgenograms were made. Microscopic sections of the involved bones were also made.

Figure 1 shows the type of plaster cast used to produce valgus deformity of the upper end of the tibia. Figure 2 shows the typical roentgenographic appearance of the tibia after twenty days in the plaster cast; some valgus deformity is already present in the upper end. Eight rabbits were used in this part of the experiment. Four were sacrificed after three weeks in plaster. Figure 3 shows the amount of valgus deformity present in rabbit no. 834, and the bones of the other three rabbits sacrificed at that time are shown in Figure 4. All have a valgus deformity of the upper portion of the tibia on the left side. The control side is normal.

In the other four rabbits in this group the deforming plaster casts were kept on for six weeks. The deformities produced after this longer period were much more marked than those produced after the shorter period. Figure 5 shows the deformity in rabbit no. 462. The portion of Figure 5 which shows the smaller left tibia was cut out of the original roentgenogram of rabbit no. 462 (made just before the experiment began) and was inserted into this roentgenogram in order to show the relative lengths of the tibia before and after the experiment. It is apparent that all the deformity occurred in the part of the bone laid

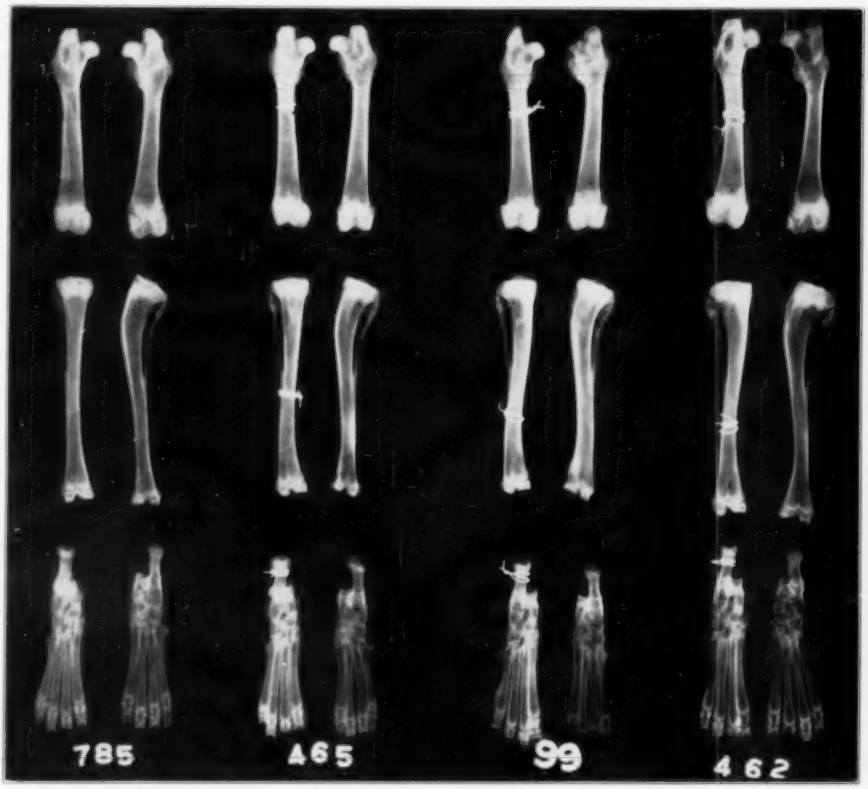

FIG. 6

Roentgenogram showing the deformities which developed in the left posterior extremities of rabbits following six weeks in plaster casts. The left extremities are on the right. The right (control) extremities are marked by wire (except for the right extremity of rabbit no. 785, in which a silk suture was used). In addition to the angular deformities described in the text, there also developed disuse atrophy of the left extremities. This atrophy, which was most apparent in the foot bones, was also present after three weeks in plaster. See Fig. 4.

down since the experiment began; the shaft itself did not bend. Since no fracture occurred, the deformity must be the result of a differential rate of growth, produced by the stresses applied by the plaster. That portion of the epiphyseal plate compressed by the valgus strain grew relatively more slowly, while the opposite side grew more rapidly. The bend in the fibula shows similar characteristics.

Roentgenograms of the posterior extremities of the four rabbits which were kept in plaster for six weeks are shown side by side for purposes of comparison (Fig. 6). Nearly all of the angular deformities in these rabbits are concentrated in the upper portion of the tibia, the region in which, as the photographs and roentgenograms show, most of the stress fell. Rabbits no. 465 and no. 99 also show excessive deformities in the region of the lower tibial epiphysis. These deformities are probably due to pressure sores which developed under the plaster cast and extended into the underlying bone. None of the other rabbits in these experiments developed pressure sores.

Figures 7 and 8 show the microscopic appearance of the upper portion of the tibia at the end of three and six weeks respectively. The changes shown in the latter figure are more marked than those shown in the former. The curvature of the upper end of the bone, which is well shown, indicates that there was a diminution in the rate of growth of

FIG. 7

FIG. 8

Fig. 7: Microscopic section of the upper end of the tibia of rabbit no. 834 following three weeks in plaster. (See Fig. 8.)

Fig. 8: Microscopic section of tibia of rabbit no. 785 following six weeks in plaster. The side of the epiphyseal line which appears on the right was compressed and its growth slowed. The opposite side, relieved of pressure, shows overgrowth. The difference in the rate of growth is recorded in the curvature of the upper end of the shaft. There is a marked increase in the trabeculation on the side upon which the pressure was increased (*A*) and a corresponding decrease in the number and thickness of the trabeculations on the side upon which the pressure was diminished (*B*). This is in accord with Wolff's law. The epiphyseal growth plate is not significantly narrowed.

the lateral half of the epiphysis, where pressure was produced by the plaster. The opposite or medial side, where the pressure was released, shows overgrowth of bone. There is no marked change in the thickness of the epiphyseal plate on either side. The most striking phenomenon, aside from the curvature, is the marked increase in trabeculation in the area subjected to increased pressure and its decrease in the area relieved of pressure (areas *A* and *B* in Fig. 8). Figure 8 is a dramatic illustration of the apparent paradox (no real contradiction exists) between Wolff's law and Delpech's law: increased pressure in the long axis of a growing bone results in greater growth in thickness (hypertrophy) but diminished growth in length.

Postural Deformities

Figure 1 illustrates the characteristic posture assumed by all the rabbits used in this portion of the experiment. The limb is sprawled out to the side and cannot be brought under the animal's body when the animal is in the usual crouched resting position. In order to determine whether the maintenance of this position alone, without any stress being produced by the plaster cast, could cause valgus deformity of the tibia, shorter

plaster casts were applied to two rabbits. These casts stopped well below the knee and exerted no direct stress upon the upper end of the tibia (Fig. 9). As Figure 10 shows, they enforced a position of habitual postural valgus upon the leg of the animal and resulted, at the end of six weeks, in a definite valgus deformity of the upper portion of the tibia, similar to, but much milder than, that induced by the plaster cast (Fig. 11, rabbits no. 441 and no. 496; compare with Fig. 6).

The essential deforming force here is not the plaster, since it stopped well short of the area in which the valgus deformity occurred. Moreover, it is hard to imagine any abnormal muscular force which could pull the flexed tibia into a valgus position. It would seem, therefore, that the animal's weight (and only a part of that, judging from Figure 10) and the weight of the plaster-encased extremity must be held responsible for the deformity. Hence, these deformities were produced, in the last analysis, by gravitational forces of which the normal pattern of distribution had been distorted by the abnormal posture enforced by the plaster.

Angular Equivalents of Asymmetrical Epiphyseal Growth

When a pressure differential exists between the two sides of a single epiphyseal plate, unequal growth will occur, with angulation. The degree of angulation which occurs will have a simple relationship to the total amount of overgrowth which is present on one side of the epiphysis and to the diameter of the bone. This relationship is illustrated in the diagram in Figure 12. This diagram shows the end of a long bone and its epiphyseal line, *AC*, the

Fig. 9: Roentgenogram, made seventeen days after the start of the experiment, showing the leg of rabbit no. 496 in a plaster boot. Some valgus bending of the portion of the leg above the plaster is apparent.

FIG. 9

FIG. 10

Photographs of rabbit no. 496 upon which a plaster boot was applied. The habitual position of the leg, enforced by the plaster, is shown.

diameter of which is indicated by d. Imagine that the epiphysis is stapled at C so that growth is stopped at this point. The opposite side of the epiphysis will continue to grow, describing the arc AB. When the extent of this unilateral overgrowth equals the diameter of the shaft, the epiphysis will be in the position BC. Then ABC will be an equilateral triangle, and the angle at C will be 60 degrees. Hence a unilateral overgrowth which is equivalent to the diameter of the shaft will lead to an angulation of 60 degrees (actually somewhat less *, but the figure 60 is close enough for all practical purposes). Smaller overgrowths cause proportionately smaller angulations, that is, an overgrowth equivalent to one-third of the shaft will produce a 20-degree angulation. This quantitative relationship may have some practical applications: for example, will unilateral stapling correct a 60-degree angulation in a bone two inches in diameter, when only one inch of growth remains?

For the same amount of unilateral overgrowth, a bone twice as thick will show half as much angulation, while one half as thick will show twice as much angulation. The narrower thoracic spine will curve more than the lumbar spine, given the same amount of unilateral-growth discrepancy (all other factors being disregarded). In a similar manner, it is possible to explain why the prognosis for a long slender foot is better than that for a broad stubby one in the correction of club-foot. When small bones and rapid growth are combined, as in infants, angular deformities can be produced and corrected very rapidly, which gives the illusion that the infant skeleton is extremely plastic.

THE EFFECT OF PRESSURES PERPENDICULAR TO THE AXIS OF EPIPHYSEAL GROWTH

Relatively little work has been done on the effects of pressure applied perpendicular to the axis of epiphyseal growth. Appleton's work indicated that torsional deformation follows muscle section, but the mechanism by which this deformity develops has not been explored. The experimental work outlined below indicates that pressure applied perpendicular to the axis of epiphyseal growth (perpendicular to the long axis of a long bone) changes the direction of such growth. The amount of this change of direction varies with the degree of pressure and the diameter of the bone. Pressures applied in any direction between the perpendicular and the parallel may be broken down into vector components, and the proportionate effect of each component on rate and direction of growth may be determined.

In an earlier article [3], it was suggested that some of the torsional deformation of vertebrae which occurs in scoliosis is caused by the deflection of growing epiphyseal cartilage columns in a manner analogous to the deflection of water entering a flowing stream. This type of deflection is illustrated in Figure 13, which shows an epiphyseal plate of a rabbit approximately six weeks old.

The preparation was obtained by sacrificing the animal, isolating the long bone, and applying pressures in the directions illustrated by the arrows by means of a metal clothespin spring (Fig. 14). The bone, with the spring *in situ*, was then fixed in formalin and decalcified. Following this procedure the metal spring was removed and sections were cut along the plane in which the forces were applied. It was found that the angulation occurred at the junction of the metaphysis with the epiphyseal plate and that it varied according to the degree of pressure that had been applied. To confirm these relationships a small section was excised from the upper end of a fresh calf tibia, the epiphyseal line and the bone immediately above and below the epiphyseal line being included. Two marker needles

* $\frac{360}{2\pi}$, or about 57 degrees. If a growing epiphysis is stapled on one side only, the diameter of the epiphyseal plate will represent the radius of a circle which has its center at the staple. Unilateral growth in length will be along the circumference of this circle. To determine the angulation of the resulting deformity, the following formula may be used: angle = $\frac{\text{unilateral overgrowth}}{\text{circumference}} \times 360$. If the overgrowth equals one radius, then the formula will read: angle = $\frac{\text{radius}}{2\pi \text{ radius}} \times 360$ or $\frac{360}{2\pi}$ or approximately 57 degrees.

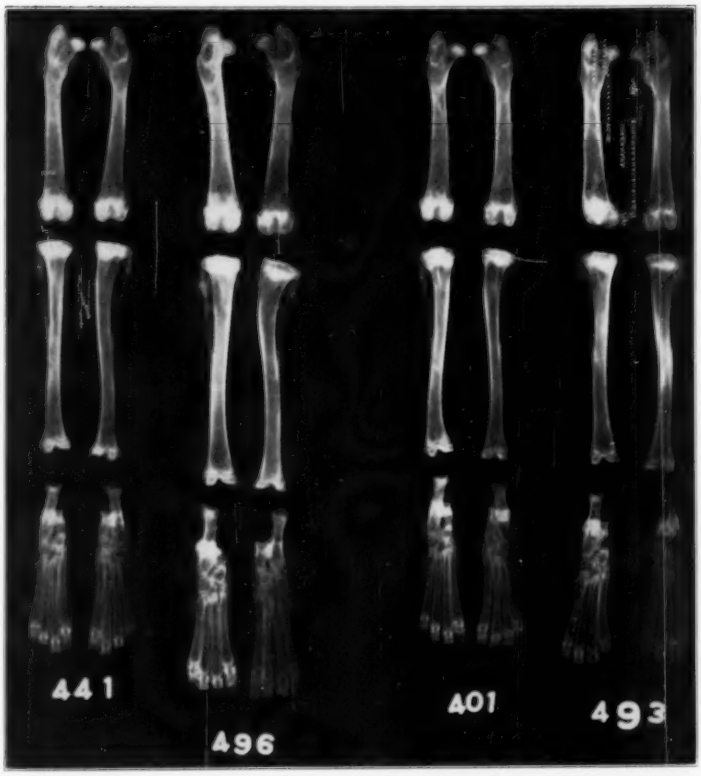

FIG. 11

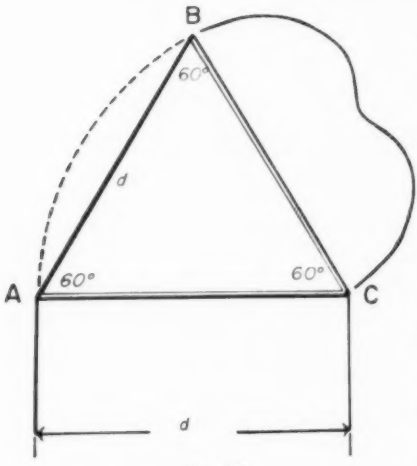

FIG. 12

Fig. 11: The roentgenograms of rabbits no. 441 and no. 496 show the postural valgus deformities which developed in the upper tibiae following the use of the type of plaster cast shown in Fig. 10. The controls are shown on the left.

The roentgenograms of rabbits no. 401 and no. 493 show the typical appearance of extremities subjected to torsional deformation. A photograph of the tibiae of these rabbits is shown in Fig. 18.

Fig. 12: Diagram of asymmetrical growth. See text for explanation.

were drilled into the bone on either side of the epiphyseal line. Deflection of the epiphysis in a direction parallel to the epiphyseal line could then be measured by observing the motion of the points past each other. Forces were applied by a spring scale in a direction perpendicular to the epiphyseal columns and the deflection was observed under the dissecting microscope. It was found that the epiphysis behaved as an elastic body, for the deflection was proportional to the forces applied and the epiphysis returned to its original position the moment the forces were removed. A deflection of approximately 30 degrees, as shown in Figure 13, was achieved with difficulty, the force required to obtain this deflection being approximately two kilograms per square centimeter of epiphyseal surface. This

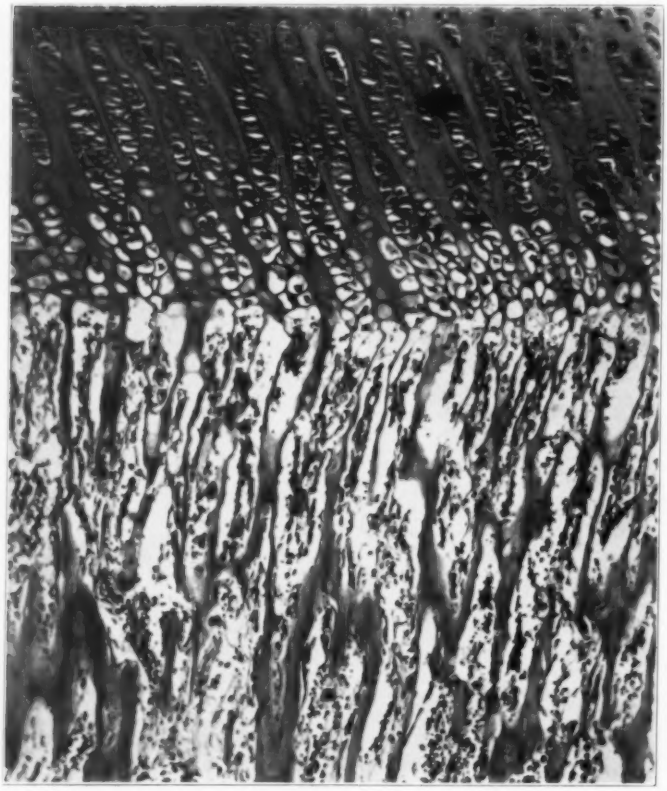

FIG. 13

Fig. 13: High-power view of the junction of the epiphysis and metaphysis in the bone illustrated in Fig. 15. The bone trabeculae of the metaphysis appear at the bottom of the photograph while the down-growing cartilaginous columns of the epiphysis appear above. The acute angulation which developed at the junction of these two regions can be clearly seen. (Figs. 13, 14, 15, and 16 were made during an earlier experiment.)

FIG. 14

Fig. 14: Roentgenogram showing the use of a metal clothespin to apply forces to the epiphyseal plate. The direction of the forces is indicated by the arrows. (This bone is not the one which appears in Figs. 13 and 15.)

deflection would be more difficult to attain in an intact epiphyseal plate because of irregularities in the contour of the plate which interdigitate and tend to limit lateral motion. It seems, then, that the deformation illustrated in Figure 13 is of extreme degree, greater than that which occurs in response to stresses *in vivo*.

The cartilage columns, deflected by forces perpendicular to their direction of growth, will continue to grow out, calcify, and be converted into bone. So long as the deforming force is maintained, however, this new growth will be deflected, resulting in a lateral displacement of the epiphysis, which, on a

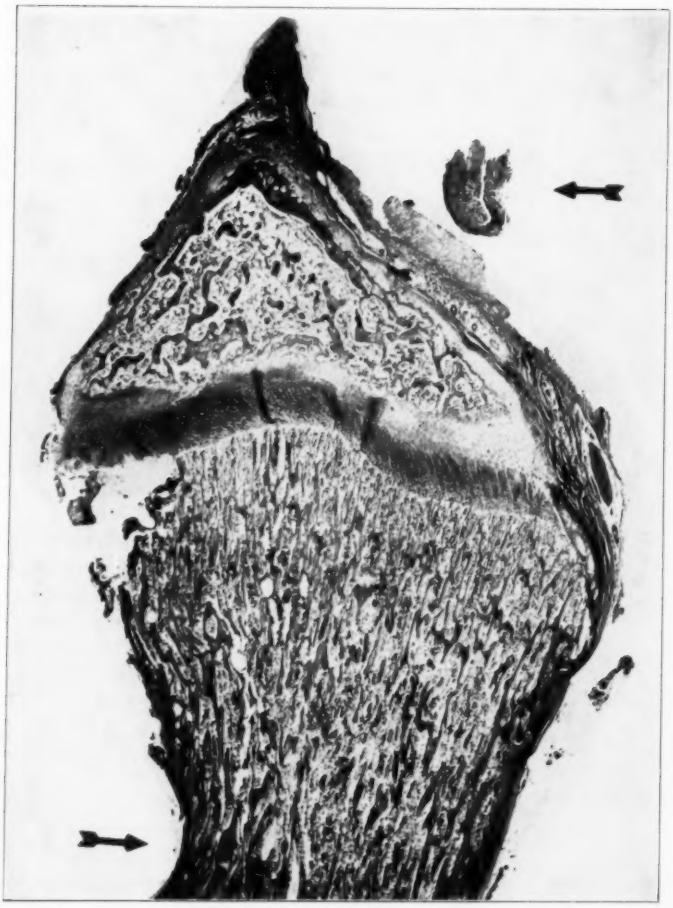

FIG. 15

Low-power view of bone shown in Fig. 13. The direction of the forces is indicated by the arrows. Note the indentation of the cortex which was caused by the spring; this probably occurred during decalcification of the specimen.

roentgenogram, will resemble the picture of a slow slipping of an epiphysis, such as that illustrated in Figure 16.

Torsion

A torsional stress will lead to deflection, either clockwise or counter-clockwise, of the columns around the circumference of the epiphyseal plate. As the new bone is formed, it grows away from the epiphysis in a spirally twisted pattern, eventually resulting in a torsional deformation. This is the basis of the internal-rotation deformation which developed after section of the external rotators of the femur in Appleton's growing rabbits. The authors have produced similar deformities by the application of plaster casts, a method which yields more marked deformities in less time than does muscle section.

Plaster casts were applied to the left hind legs of young rabbits in the position of maximum internal (rabbit no. 493) and external (rabbit no. 401) rotation of the foot on the tibia, the casts extending from the toes to as high as possible on the femur. The posi-

tions enforced by the plaster are shown in Figure 17. The plasters were changed or were sectioned and rotated into positions of increasing deformity at weekly intervals. The rabbits were sacrificed six weeks after the start of the experiment, and the bones of the lower extremity were removed for examination. The torsional deformations produced in the affected tibiae are well shown in Figure 18, which contrasts the internal and external rotation deformities. Roentgenograms of all the bones of both hind legs are shown in Figure 11.

Postural Torsional Deformities

Just as postural abnormalities can produce valgus deformities (Figs. 9, 10, and 11), so can they produce torsional deformities. A re-examination of Figure 1 will show that in addition to producing a valgus stress in the tibia, the characteristic posture enforced by the plaster also produced a torsional stress in the femur, this stress being in the direction of internal rotation of the lower end against the upper end. This stress was not produced by the plaster, which did not extend across both ends of the femur; gravity was the deforming force, just as it was in the production of postural valgus of the tibia.

FIG. 16

Fig. 16: Roentgenogram showing the posterior displacement of an upper tibial condyle. The appearance of this deformity is similar to that of an epiphysis which has slowly slipped as the result of distraction of the bent knee by the plaster. The control is shown on the right.

The degree of torsional deformation obtainable by this means is illustrated in Figure 19. This photograph illustrates the postural torsional deformities of the femur accompanying the plaster-induced valgus deformities of the tibiae in the four rabbits whose roentgeno-

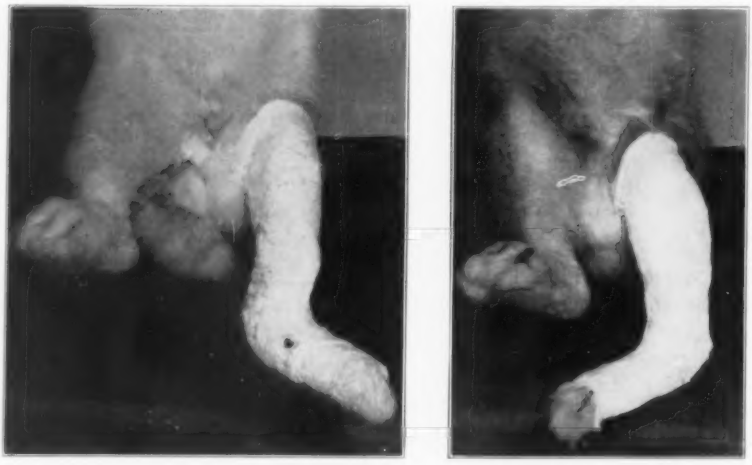

FIG. 17

Positions of external and internal rotation of the foot on the tibia produced by plaster casts. Rabbit no. 401 is shown on the left, rabbit no. 493 on the right.

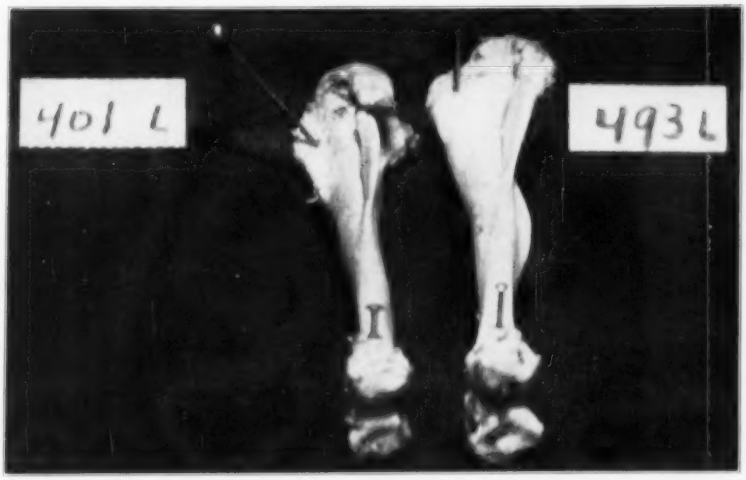

FIG. 18

Photograph showing the torsional deformities which developed in the left tibiae of rabbits no. 401 and no. 493 following use of the plaster casts shown in Fig. 17. The lower pins have been placed parallel to the transverse axis of the ankle joints; the upper pins have been placed parallel to the transverse axis of the knee joints.

grams are shown in Figure 6. Figure 20 shows one of these femora in more detail and indicates that the torsional deformities, like the valgus deformations discussed earlier, occurred only in that section of the bone which had been laid down since the experiment began. This has been confirmed by comparison of the later roentgenograms of the femora with the original roentgenograms made before the start of the experiment. That of rabbit no. 462, for example, shows that the straight section of shaft shown by the crayon line in Figure 20 constituted the entire diaphysis at the start of the experiment. Incidentally, the authors see no difference, save one of degree, between this type of postural torsional deformation and that described by Knight and Kite as occurring in the lower extremities of children as a result of their sleeping positions. Gravity is the sole deforming force in both cases.

Geometrical Analysis of Torsional Deformations

As is true in the production of angular deformities, the ease with which torsional deformities can be produced is theoretically in inverse proportion to the width of the bone.

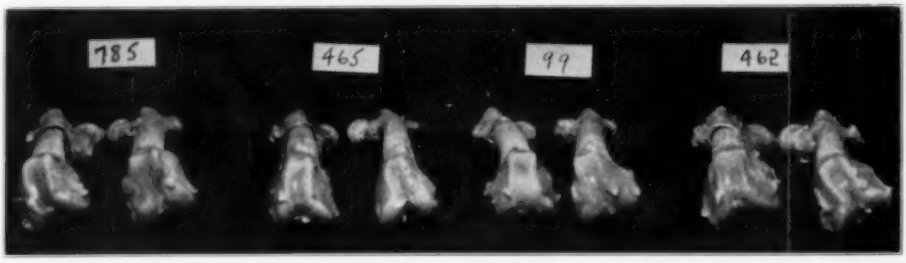

FIG. 19

Postural (gravitational) deformities resulting from the position of the leg shown in Fig. 1. In each rabbit the lower end of the femur has been internally rotated against the upper end. The opposite femora, included for comparison, appear on the left.

FIG. 20

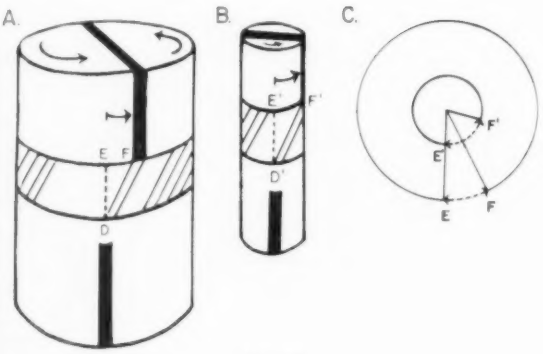

FIG. 21

Fig. 20: Detailed view of the femora of rabbit no. 462, which are also shown in Fig. 19. This photograph was made from above, and the distal ends of the bones appear at the top. The control bone is shown on the right. The ridge along the lateral border of the posterior surface of each femur has been marked by a crayon in order to indicate that the shaft does not twist; only the ends twist. Furthermore, only that portion of bone laid down by the epiphyseal plate while it was under torsional stress has been deviated. While most of this twist occurred at the lower end of the bone, some also occurred at the proximal end.

Fig. 21: The ease with which torsional deformation can be produced depends upon the thickness of the bone.

Bone *A* is twice as thick as Bone *B*; hence the deflection of one centimeter shown in each bone (*E* to *F* and *E'* to *F'*) involves a smaller proportion of Circumference *A* than of Circumference *B* and the resulting torsion in *A* is one-half that in *B*.

In brief, the degree of torsion produced by a given amount of lateral displacement of the epiphyseal columns increases as the size of the bone decreases. This is independent of the fact that the amount of deflection produced by a given torsional force also increases as the size of the bone decreases.

Diagram *C* shows the relationship from above, the larger circle representing Bone *A* and the smaller, Bone *B*. The drawings in this figure have not been made to scale, and the size of the epiphyseal columns as well as the extent of the deflection have been greatly magnified.

This is illustrated in Figure 21. The bones diagrammed are subjected to the same lateral deflection of epiphyseal columns (from *E* to *F* and from *E'* to *F'*) in response to torsional stress. In bone *B*, the diameter of which is approximately one-half the diameter of *A*, the displacement will involve twice as much of the circumference as is involved in Bone *A*, hence lead to twice as much torsional angulation. In addition to this, similar torsional forces applied externally will cause a greater deflection of the cartilage columns in a thinner bone because of factors of mechanical advantage (for example, a thread can be twisted more easily than a cable).

Any period of time during which torsional stress, with its accompanying columnar deflection, occurs (provided that some growth also takes place during that period) will result in the development of a permanent torsional deformation as the twisted cartilage columns are converted into bone. If growth takes place at a constant rate (which does not necessarily happen), then the final deformation will vary directly with the total time the cartilage columns are held in the twisted position (other things being equal), irrespective of how this time is divided. In other words, if these assumptions are correct, it would seem that ninety-six hours in a Denis Browne splint (used for correction of tibial torsion) should result in the same amount of correction whether the treatment is concentrated in four days of constant use or spread over twenty-four days at four hours per day.

In brief, a force exerted on an epiphyseal plate in a direction not parallel to the direction of growth will deflect the growth away from the deforming force. The amount of deflection produced is a function of the direction of the force, being directly proportional to the angle formed by the direction of growth and the direction of the deforming force

(up to 90 degrees). When the force is applied parallel to the direction of growth, growth is inhibited uniformly if the pressure is the same throughout the epiphyseal plate and is inhibited asymmetrically if the pressure is greater on one side than on the other. Hence pressure may modify both the rate and direction of epiphyseal growth in such a way as to give the illusion that the bone is yielding in the manner of a plastic material. This is the contribution of the epiphyseal plate to the phenomenon of "plasticity" of growing bone.

GRAVITATIONAL INHIBITION OF GROWTH

In certain bones, such as the tibia, femur, and spine in man and the tibia in rabbits, gravitational, or weight-bearing, forces are parallel to the direction of epiphyseal growth. Is there any evidence that this normal and physiological gravitational pressure has any inhibitory effect on the growth of these bones, that is, does weight-bearing slow growth and does relief from weight-bearing result in overgrowth?

The authors' observations indicate that gravitational pressure does have an inhibitory effect on the growth of bone. All of the tibiae immobilized in plaster in the authors' experiments were substantially longer than their mates. The overgrowth was apparent at the end of three weeks (Fig. 22) and became only slightly more marked at six weeks (Figs. 6 and 11). Actual measurements made on the roentgenographic plates indicated that after six weeks the average tibial overgrowth, as compared with the growth of the control, was slightly over 0.3 centimeter. (The length of the tibiae of the six-week animals averaged nine to ten centimeters at the time the animals were sacrificed.) The authors believe this overgrowth resulted from the position enforced by the plaster (Fig. 1) and that the overgrowth was produced by relief from normal weight-bearing.

Figure 23 shows the normal resting attitude of the rabbit. The tibiae are vertical and the rabbit's weight produces an axial thrust or compressive stress in the direction of epiphyseal growth. Figure 1 shows that the immobilized tibiae were released from this compression stress, which, of course, persisted relatively unchanged on the opposite or control side. Measurements made on roengenograms (Fig. 6) showed that even the concave sides of the deformed tibiae were longer than the control tibiae; indicating that the growth inhibition caused by compression of the upper epiphyses by the plaster was more than outweighed by the growth acceleration (in both the upper and lower epiphyses) caused by relief from weight-bearing.

As a check on these results, the left hind extremities of three rabbits were immobilized in plaster from above the knee to the toes. The plasters were applied with the knees and ankles fully extended, so that weight-bearing would be prevented and so that torsional or bending stresses would not be exerted by the plasters themselves. The position is shown in

FIG. 22

Fig. 22: Photograph of the left tibia of rabbit no. 834 made after three weeks in a cast which produced valgus stress and which also prevented normal weight-bearing. (Fig. 1 shows the position which was enforced by this cast.) This tibia is noticeably longer than its mate. The control tibia, shown on the left, is marked by a black suture. A roentgenogram of these bones is shown in Fig. 3.

FIG. 23

Lateral roentgenogram of a rabbit in a normal resting position. The head appears on the left. The tibiae are vertical and are bearing the rabbit's weight, the force of gravitational thrust being parallel to the long axis of the bones. The femora and feet, which are horizontal, are not subjected to any axial weight thrust. The femora may be subjected to axial compression, however, as a result of acting as a strut against active muscle pull.

Figure 24; from this figure it is apparent that it is very difficult to interrupt normal weight-bearing without producing some bending stress—in the rabbit, at any rate. The roentgenograms of these animals' lower extremities after six weeks are shown in Figure 25. In all three animals there was a mild postural valgus deformity, much less marked than that in the animals used earlier, but the tibial overgrowth persisted unchanged at 0.3, 0.3, and 0.4 centimeter respectively. The overgrowth seemed to be related to relief from weight-bearing rather than to the deformities produced by the plaster. Roentgenograms suggesting that similar gravitational overgrowth may occur in the human are shown in Figures 26 and 27.

In addition to the overgrowth in the tibiae, all of the femora on the immobilized side were equal or slightly longer than their controls, the difference averaging slightly under 0.1 centimeter. The authors believe that this overgrowth was the result of relief

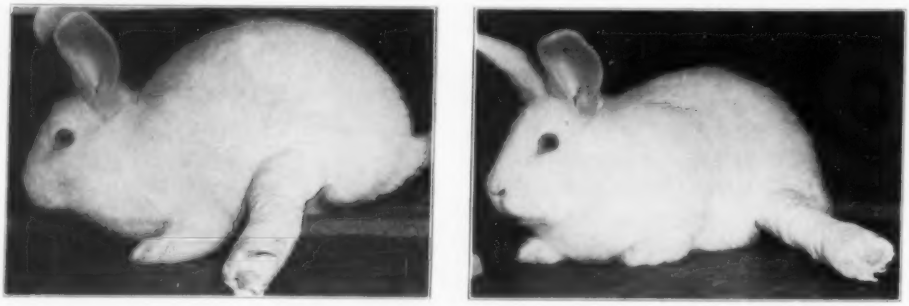

FIG. 24

Photographs showing casts applied so that they would not exert bending or torsional stresses but would interrupt normal weight-bearing. That some postural valgus stress is being exerted because of the animal's position is apparent.

FIG. 25

Roentgenograms of the hind limbs of three animals after six weeks in the type of straight plaster cast shown in Fig. 24. Overgrowth of the tibiae, as well as the presence of some postural valgus deformity, is apparent.

from the compression normally produced by the femoral muscles, which are used to maintain the position shown in Figure 23 during weight-bearing. Gravitational thrust itself is perpendicular to the axis of growth of the rabbit's femur and hence cannot affect its rate of growth.

On the other hand, all of the feet, measured from the end of the calcaneus to the tips of the metatarsals, were equal or smaller than their controls, the average difference being slightly more than 0.1 centimeter. Gravity does not affect the growth of the feet because they are horizontal in the weight-bearing positions. Furthermore, no muscle masses surround the foot, producing axial compression by their contraction, as is the case with the femur. It is suggested that this is an example of disuse undergrowth in length.

Disuse atrophy (undergrowth in thickness) is a familiar entity. In this study it was discernible in most of the bones of the immobilized extremities and was particularly noticeable in the tarsal bones, in which there was not only the usual diminution in density,

FIG. 26

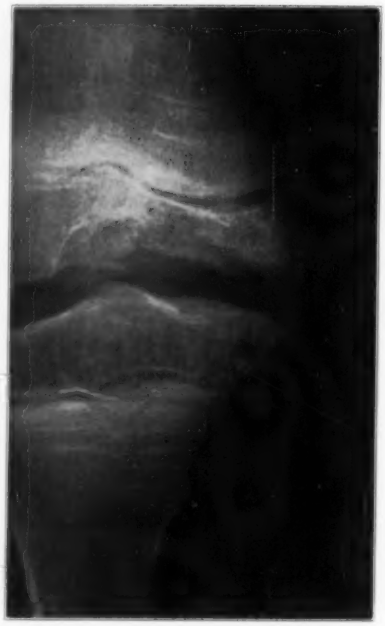

FIG. 27

Fig. 26: Roentgenogram of the knee of a fifteen-year-old boy showing overgrowth of the medial femoral condyle in the area relieved of normal weight-bearing pressures as the result of resection of the opposing tibial surface.

Fig. 27: Roentgenogram of the knee of a boy six and one-half years old. Overgrowth of the medial tibial condyle has occurred in the area relieved of normal weight-bearing pressures as the result of partial resection of the opposing femoral surface. (Courtesy of Dr. Edgar Bick.)

but also an occasional marked narrowing of the transverse diameter of the calcaneus (Fig. 11; compare rabbits no. 441, no. 493, and no. 496).

In brief, our observations indicate that there normally exists some gravitational inhibition of vertical growth in the experimental animal which is disturbed or interrupted by any procedure which interferes with normal weight-bearing. In many of the experiments which have been designed to stimulate epiphyseal growth in the experimental animal by various surgical measures, weight-bearing has unfortunately been interfered with—as a result of postoperative pain, disuse, or limp or by the use of certain types of splintage or immobilization of the limb. This interference has added a complicating factor which hitherto has not been taken into account in estimating the growth differences which have been obtained by the surgical procedures.

DISCUSSION

The material presented here indicates that pressure does not inhibit growth by an all-or-none law. Furthermore, there is no sign that there is a threshold below which pressures are ineffective. On the contrary, our observations indicate that extremely mild forces can inhibit or modify epiphyseal growth. Stresses from a plaster cast, postural stresses, even gravitational (and perhaps muscle) stresses seem sufficient to affect it; and in the case of the latter, release from these normal forces results in overgrowth. In the light of these considerations, it would seem that skeletal "plasticity", instead of being resistant to all but the greatest forces, as indicated by Strobino, is almost a "fluidity"; the lower limits of the pressure which can affect it may not be definable.

Certain aspects of protein chemistry favor this point of view. Growth in length is, of course, an example of synthesis of the protein molecule out of its constituent building blocks. Recent studies [3] indicate that this reaction is accompanied by considerable volume change, so that increased pressure would tend to inhibit the synthesis, according to Le Chatelier's law *. There is no reason to expect that there is a lower limit to the pressures which may be effective in this regard; and it may well be that any pressure, however small, may have some effect, although it may not be detectable.

Nothing in the foregoing must be construed as indicating that pressure is the only factor influencing bone growth. It is only one of a great number of factors, most of which are imperfectly understood and some of which are unknown. Among these are hereditary factors, which influence not only the rate but also the pattern of bone growth—not only do tall fathers have tall sons, but there are also recognizable similarities in bodily and facial configuration. These hereditary factors operate independently of pressure-molding. Thus, "Murray and Selby have also grafted a small basal piece of the posterior limb bud of an early chick embryo onto the chorio-allantoic membrane of an older chick, and found it develop—in the absence of its usual surroundings, and in the absence of the strains and stresses to which it is normally subject—into a well-shaped femur. It is not in dispute that the ultimate perfection of the adult bone may be attained as a result of environmental stimuli, but the original pattern is inherited and surprisingly perfect." [14]

Statistics indicate that recent generations are taller than their fathers. This suggests that better nutrition results in stimulation or prolongation of growth. A more adequate intake of any of a number of nutritional factors, including proteins and minerals as well as vitamins, may be the cause of the increase in growth. Neurotrophic or related factors may play a part in growth, as indicated by the frequency of growth discrepancies after poliomyelitic paralysis or after the occurrence of other lower motor-neuron lesions during the growth period. The authors believe that disuse, even without paralysis, may also be accompanied by inhibition of growth. Various factors such as infections, disturbance of blood supply, trauma, and other local as well as general factors may influence epiphyseal growth. In addition to these factors, a variety of experimental surgical procedures upon the bone have been reported as being effective in stimulating bone growth; the results of these experiments, however, as pointed out before, are shadowed by the fact that all the surgical procedures have been accompanied by temporary relief from weight-bearing.

Whatever other factors are operating, one thing, at least, seems clear. Pressures—even relatively slight pressures—can mold epiphyseal growth so as to give the illusion of plasticity of bone. It appears that even gravitational pressures—the normal stresses of weight-bearing—are sufficient to produce this effect. Since we are continually subject to these stresses, we are all foreshortened vertically by the action of gravity and actually look (to choose an extreme illustration) somewhat like the hammered-down reflections we see in the mirror at the amusement park. This inhibition is so universal and so ubiquitous that it has not been recognized; it is the norm. Only when gravitational pressures fall asymmetrically or unequally, allowing growth to spurt in the decompressed area, do we have an indication of how our growth is being curbed by the gravitational cord of Mother Earth.

CONCLUSIONS

1. When a growing epiphysis is subjected to a stress, the rate or direction of the growth of that epiphysis or both are modified so as to yield to that stress.

2. Pressures applied in directions parallel to the direction of epiphyseal growth inhibit the rate of such growth. While considerable pressures are necessary to stop cartilaginous

* The law of physical chemistry which states that when a system in equilibrium is subjected to a stress, the equilibrium is displaced so as to yield to the stress. (The resemblance to Delpech's law is not fortuitous; the one is the orthopaedic expression of the other.)

growth completely, slight or even intermittent pressures can slow or hinder it. The gravitational pressures of normal weight-bearing seem to slow cartilaginous growth in vertical weight-bearing bones; escape from normal weight-bearing stresses results in overgrowth.

3. Pressures applied in directions perpendicular to the direction of epiphyseal growth deflect the direction of such growth, resulting in lateral or spiral (torsional) displacement of the newly laid-down bone.

4. The ease with which angular or torsional deformities may be produced in a growing bone varies inversely with its diameter. The narrower the bone, the greater its "plasticity".

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The Effect of Staples and Longitudinal Wires on Epiphyseal Growth*

An Experimental Study

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The problem of correction of unequal lengths of the lower extremities of children has been approached surgically by a variety of techniques. Shortening of the fully grown longer extremity has become an accepted procedure[17,19], but many orthopaedic surgeons prefer some type of epiphyseodesis performed during growth[2,6,11,14,15,20]. Growth expectancy curves have been established[1,6,16,20] so it can be predicted that epiphyseodesis of the type introduced by Phemister[14,15], when performed at the appropriate age, will usually result in correction of limb-length inequality.

In 1945 Haas[7] noted experimentally that a wire loop around the epiphyseal plate caused growth retardation, and that when the wire broke, growth resumed. In the same year Blount[1] introduced the use of rigid staples to clinical orthopaedics. In later publications, Haas[8] measured gross deformities resulting from stapling of dogs, and Blount and Clarke described the staple technique for the correction of limb-length inequality and angular deformities at the epiphysis in children. They noted that growth resumed when the staples were removed. The advantages of stapling over other methods of epiphyseodesis were described by Blount as being (1) a less extensive operation with less risk of complications than in other operative methods of controlling bone growth, (2) a procedure not dependent upon frequently unreliable growth-expectancy tables, and (3) the certainty of resumption of growth upon removal of the staples.

FIG. 1

Roentgenogram of a lower femoral epiphysis of a rabbit stapled for six weeks. There is a lower femoral deformity caused by retardation of growth on the stapled side and continued growth on the unstapled side. The staple was *in situ* for a sufficient period of time to produce spontaneous epiphyseodesis. This particular staple was designed with a loop for easy removal.

Another use of metal at the epiphyseal plate has been in the fixation of the slipped upper femoral epiphysis to prevent further displacement until closure of the plate occurs[13,21]. Transepiphyseal wires are commonly used without fear of interfering with epiphyseal growth in the temporary fixation of juxta-epiphyseal fractures that are unstable.

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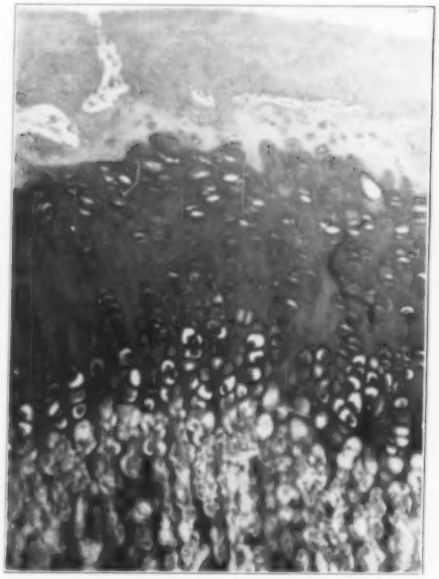

FIG. 2-A

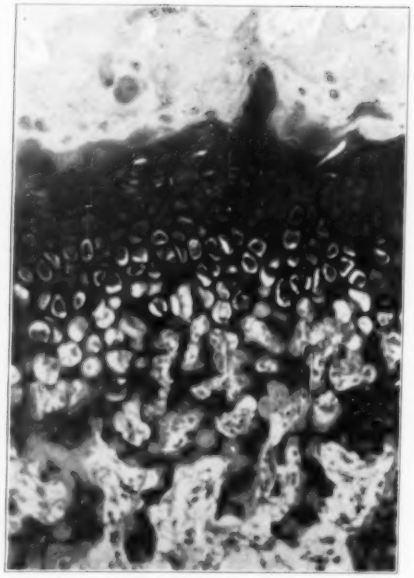

FIG. 2-B

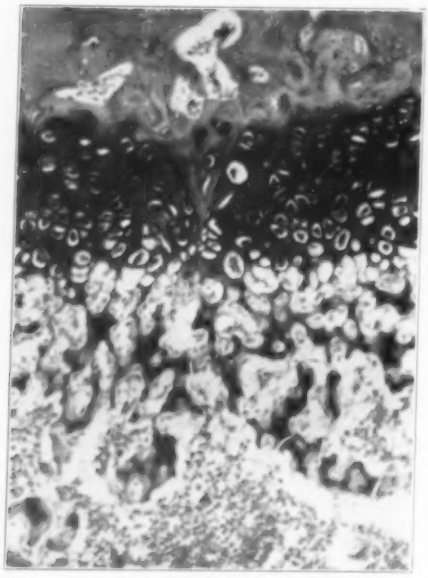

FIG. 2-C

Figs. 2-A through 2-E: The effect of stapling on cartilage-cell growth of the lower femoral epiphyses in rabbits.

Fig. 2-A: The appearance of a normal epiphyseal plate. Note the orderly arrangement of the resting, proliferating, palisading, hypertrophying, and degenerating cells, the invasion by metaphyseal vascular channels and osteoblasts, and the formation of long, thin metaphyseal trabeculae.

Fig. 2-B: The appearance of an epiphyseal plate directly under a staple *in situ* for two weeks. The palisading cells are beginning to mature and to hypertrophy, eventually to degenerate and to be invaded by metaphyseal vascular channels, thus progressively thinning the epiphyseal plate. As a result of pressures caused by the staple within the epiphyseal plate there is no new cartilage-cell formation from the zone of resting cells and proliferating cells, and there is subepiphyseal bone condensation.

Fig. 2-C: The appearance of an epiphyseal plate directly under a staple *in situ* for four weeks, with further thinning of the plate.

To hasten epiphyseal closure after slipping has occurred, bone-peg and grafting procedures have been devised[10,12]. Continued growth following nailing of slipped epiphyses[13,18] clinically, and transepiphyseal metal fixation experimentally[5,9] has been noted. The present experiments were designed to investigate the histological response to these two forms of metal fixation, staples and transepiphyseal wires, in surgery involving the epiphyseal plate.

STAPLE EXPERIMENTS

Method

Forty-four staple experiments were performed. New Zealand or Chinchilla rabbits

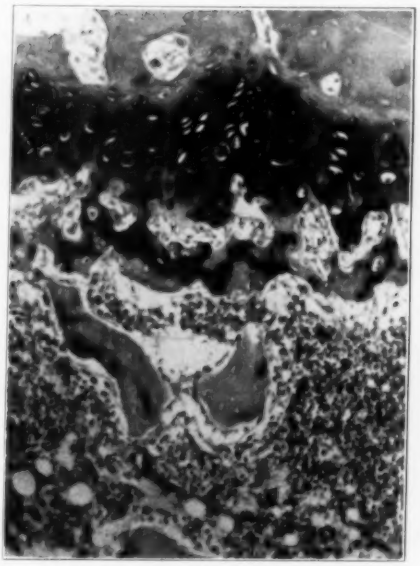

FIG. 2-D

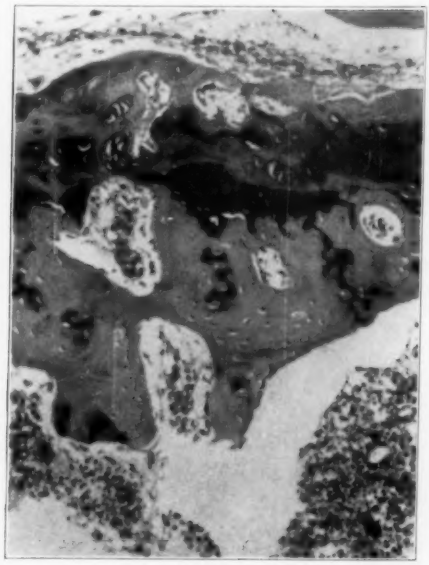

FIG. 2-E

Figs. 2-D and 2-E: The appearance of the epiphyseal plate directly under a staple *in situ* for six weeks. There is evidence of early epiphyseodesis as the remaining resting and proliferating cells mature into palisading, hypertrophying, and degenerating cells, to be replaced by metaphyseal new-bone formation (hematoxylin and eosin, × 100).

(Note: Similar findings are noted in a single epiphyseal plate stapled for six weeks. Fig. 2-A represents the appearance of the unstapled side and Fig. 2-E the stapled side. Figs. 2-B, 2-C, and 2-D represent the appearance of the intervening area, and show the effect of varying amounts of staple pressure. In the control animals, when unilateral epiphyseodesis was produced by curetting, identical graded pressure effects across the plate were noted.)

were used, about two kilograms in weight and six weeks of age. After routine surgical preparation, the animals were lightly anaesthetized with intravenous nembutal supplemented by ether inhalation, small longitudinal incisions were made over the medial aspect of the distal portion of the femora, and the distal femoral epiphyseal plates were identified. Small stainless-steel staples, fashioned from Kirschner wires (five sixty-fourths of an inch in diameter) were inserted across the distal femoral epiphyses, and no immobilization was used. There were sixteen controls in which the medial side of the epiphyseal plate was thoroughly curetted to create a unilateral epiphyseodesis. Postoperatively, each animal was given a single dose of 300,000 units of procaine penicillin intramuscularly; no infections were observed. The animals walked on the limbs operated upon a few hours after surgery. They were sacrificed at two, four, and six weeks postoperatively. The specimens were studied roentgenographically, and microscopically by hematoxylin and eosin, Van Gieson, alkaline-phosphatase, and toluidin-blue staining techniques.

Results

Roentgenograms showed that in all the animals some degree of angulation of the distal femoral epiphysis developed, manifested clinically by a bow-leg deformity. At the end of six weeks, four animals showed evidence of spontaneous epiphyseodesis under the staple (Fig. 1). The specimens were studied histologically at two, four, and six weeks postoperatively to note the effect of comparative degrees of pressure across the epiphyseal plate from the unstapled to the stapled side, and to observe the changes of the epiphyseal plate directly under the staple. The changes due to pressure under the staple at two, four, and six weeks were similar to those noted in the six-weeks-old stapled epiphyseal

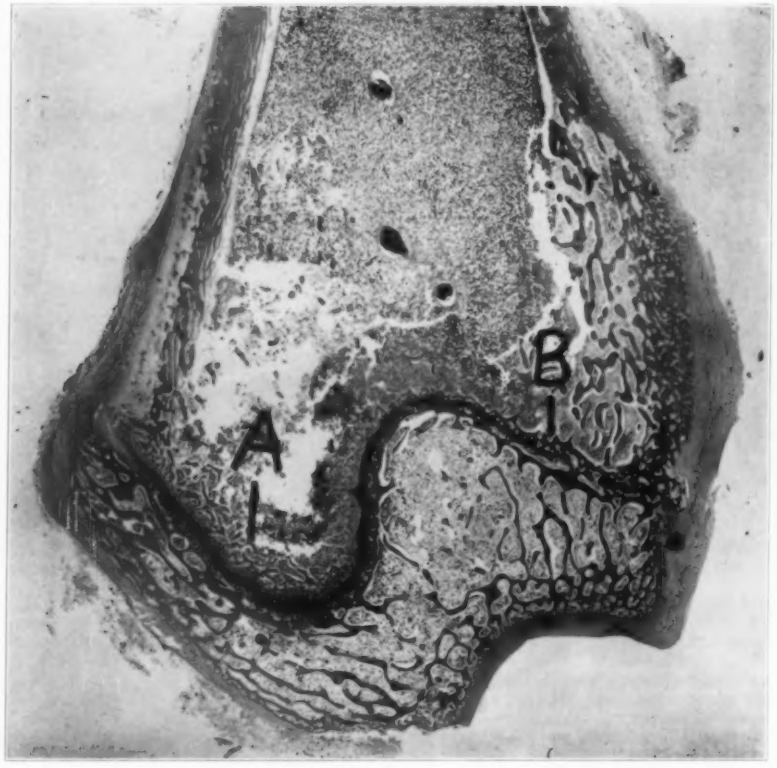

FIG. 3

Histological section of a lower femoral epiphysis of a rabbit stapled for six weeks. There is continued growth on the stapled side, *A*, and retardation of growth under the staple, *B*. Note the presence of fine metaphyseal trabeculae on the unstapled side. On the stapled side these have been replaced by a zone of subepiphyseal bone condensation under the staple with gross irregularity and thinning of the epiphyseal plate (hematoxylin and eosin, × 6).

plate when the plate in the unoperated side was compared with areas of the operated plate near the staple and, therefore, under pressure. Gradations of pressure effects were noted at various distances from the area of unilateral epiphyseodesis in the controls.

The effect of stapling, in general, was an inhibition of longitudinal growth, which, histologically, was manifested by failure of the resting cells of the epiphyseal cartilage to proliferate and to form new cells. All the existing cells of the plate, however, continued to mature, hypertrophy, and degenerate eventually without being replaced by a layer of proliferating and palisading cells. Each layer of cartilage cells that matured, hypertrophied, and degenerated in turn became vulnerable to invasion by the metaphyseal vascular

Fig. 4: Roentgenogram of a lower femoral epiphysis of a rabbit stapled for six weeks, illustrating the histological findings in Figure 3. Note the fine metaphyseal trabeculae on the unstapled side *A*, replaced by a zone of subepiphyseal bone condensation under the staple *B*, with early gross thinning of the epiphyseal line.

Figs. 5-A through 5-C: Roentgenograms demonstrating the effect of wires placed through the upper tibial epiphysis in rabbits.

Fig. 5-A: The position of the wire immediately after the operation.

Fig. 5-B: Two weeks postoperatively. In this experiment the epiphysis has continued to grow despite the presence of the transepiphyseal wire, so that now the wire is at the level of the epiphyseal plate. Seen roentgenographically, new-bone growth has filled the space formerly run through by the wire *A*.

Fig. 5-C: Four weeks postoperatively. Here the epiphysis has grown beyond the wire. Bone has replaced the defect made by the wire *A*.

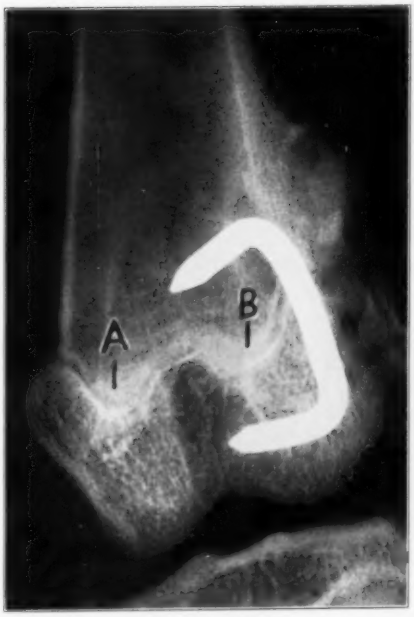

FIG. 4
(See page 1080)

FIG. 5-A
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FIG. 5-B
(See page 1080)

FIG. 5-C
(See page 1080)

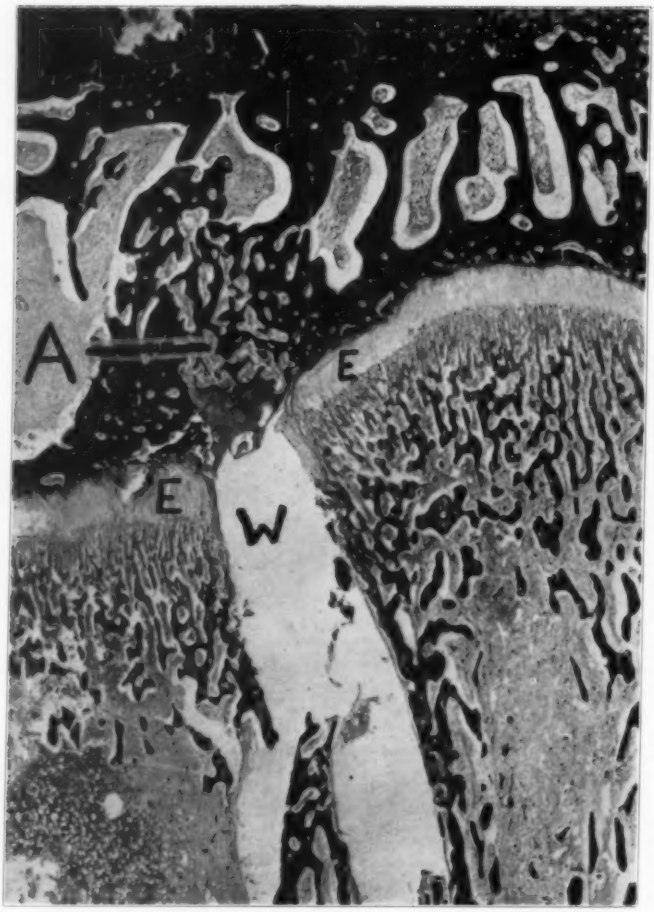

FIG. 6-A

Figs. 6-A and 6-B: Histological sections demonstrating the effect of wires placed through the upper tibial epiphysis of rabbits.

Fig. 6-A: Two weeks postoperatively. The epiphysis has continued to grow to approximately the same degree noted in Fig. 5-B. The wire was removed for histological sectioning *W*. The space in the epiphysis formerly run through by the wire is now filled by bone *A*. The wire is at the level of the epiphyseal plate *E* (hematoxylin and eosin, × 60).

channels. The epiphyseal plate, therefore, became progressively thinner and thinner, until complete obliteration with epiphyseodesis occurred (Figs. 2-A through 2-E).

Since longitudinal growth was mechanically blocked by the staple, the newly forming metaphyseal bone accumulated as an increasingly mature and dense layer of bone bordering on the metaphyseal side of the epiphyseal plate. The slight amount of cartilage-cell proliferation that did occur within the plate was subjected to the internal pressures of the staples, as manifested by occasional isolated areas of irregularly arranged cartilage cells in the form of small "nests."

To determine at what point the arrest of cellular proliferation was still reversible would be of clinical value, so that removal of the staples might always be depended upon to result in resumption of normal growth. Certain warning signs were noted in the experi-

FIG. 6-B

Four weeks postoperatively. Here the epiphysis has grown beyond the wire to the degree illustrated in Fig. 5-C. The wire was removed for histological sectioning *W*. The wire is replaced by a transepiphyseal plug of bone *A* causing local epiphyseodesis across the epiphyseal plate *E* (hematoxylin and eosin, × 60).

mental rabbits which might be of value clinically in determining the point at which changes become irreversible and epiphyseodesis occurs. Three of these warning signs observed histologically are visible roentgenographically under the staple, either singly or simultaneously prior to spontaneous epiphyseodesis (Fig. 3). These are (1) the disappearance of the fine metaphyseal trabecular pattern, to be replaced by (2) a subepiphyseal line of bone condensation, with finally (3) thinning of the epiphyseal line (Fig. 4).

TRANSEPIPHYSEAL WIRE EXPERIMENTS

Similar rabbits were used in this experiment. In twelve rabbits an incision was made over the medial aspect of the upper portion of the tibia and a Kirschner wire, five sixty-fourths of an inch in diameter, was inserted into the medial cortex three-fourths of an inch below the epiphyseal plate. The wire was passed proximally through

FIG. 7

FIG. 8-A

Fig. 7: Roentgenogram of the upper tibial epiphysis of a rabbit, four weeks after crossed wires were placed across the epiphyseal plate, demonstrating the ineffectiveness of this type of epiphyseodesis. The epiphysis has grown away from the wires leaving an area of bone condensation *A*. In some instances the wires separated, one remaining in the epiphysis and the other in the metaphysis.

Figs. 8-A and 8-B: The effect of eccentric curettage of the epiphyseal plate.

Fig. 8-A: Roentgenogram of the upper portion of the tibia of a rabbit in which a small curette was inserted into the medullary canal and the medial portion of the epiphyseal plate was curetted. Partial retardation of growth resulted in this deformity which was noted six weeks later. The line of eccentric central epiphyseodesis is seen at *B*. Continued, but retarded growth occurred from the uninvolved peripheral portion of the plate *A'*. Normal growth from the lateral portion of the plate *A* created the varus deformity.

the center of the epiphyseal plate. The excess portion of the wire was removed. The animals were sacrificed at two, four, and six weeks after operation, and the specimens were studied roentgenographically and microscopically, the hematoxylin and eosin stain technique being used. Additional experiments were performed on twelve animals. These were carried out to study the effectiveness of crossed wires in retarding epiphyseal growth.

A wire was inserted into the medial tibial cortex just below the proximal tibial epiphyseal plate, and directed towards the proximal and lateral corner of the epiphysis. A similar wire was inserted through the cortex of the medial portion of the upper tibial epiphysis above the epiphyseal plate and was directed distally and laterally, crossing the first wire at about the center of the epiphyseal plate, in a manner similar to the experiments of Haas [9]. As a control, a drill hole was made in the medial tibial cortex three-fourths of an inch below the epiphyseal plate. A small curette was inserted into this hole and directed towards the epiphyseal plate. The plate was then curetted centrally and eccentrically in twenty-two experiments. A seven sixty-fourths of an inch drill-hole was made through the epiphyseal plate, a Kirschner wire being used instead of a curette in twelve experiments.

Results

Roentgenograms of the rabbits showed that in no instance did the single trans-epiphyseal wire interfere with the growth of the epiphysis (Figs. 5-A through 5-C).

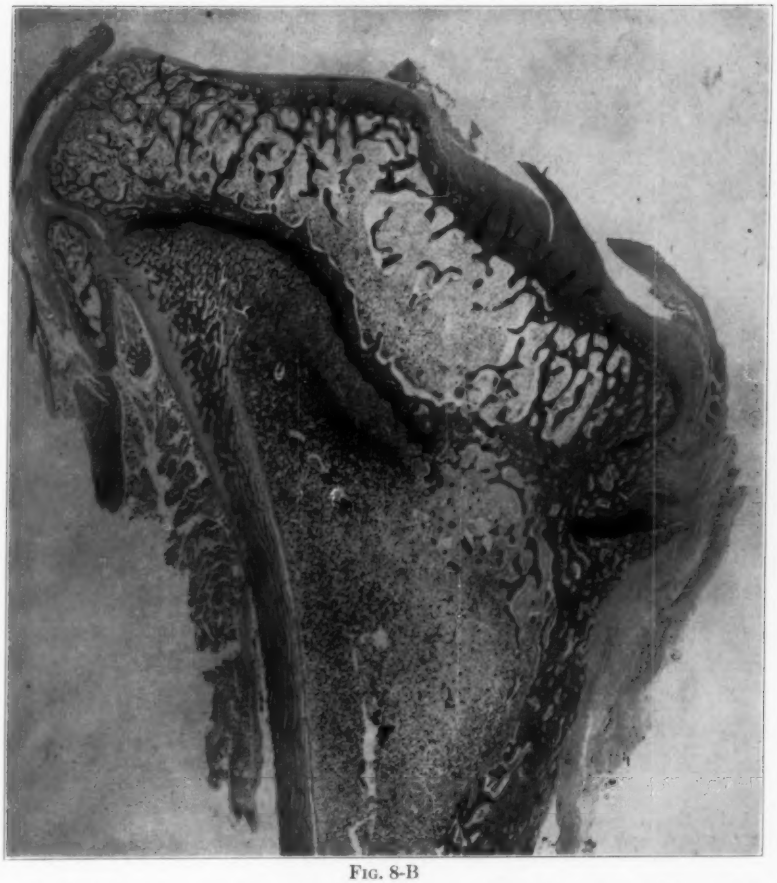

FIG. 8-B

Histological section of a specimen similar to Fig. 8-A. Eccentric central epiphyseodesis has occurred, causing a varus deformity (hematoxylin and eosin, × 6).

Histologically, there was no foreign-body reaction to the wire, and a unicellular, endothelial-like layer came to lie between the wire and the bone. The epiphyseal plate, adjacent to the wire, showed no foreign-body reaction. As the epiphysis grew away from the wire, the path made by the wire was replaced by bone. At the level of the epiphyseal plate itself, bone formation and not epiphyseal cartilage proliferation occurred, causing a column of bone, the size of the wire, to form across the epiphyseal plate (Figs. 6-A and 6-B).

A clinical observation, related to this study, was a nailed, slipped upper femoral epiphysis which overgrew the nail but did not reslip. It is suggested that the transepiphyseal column of bone which formed in the defect made by the nail was large enough to offer stability against reslipping, but not large enough to interfere with growth.

Crossed wires failed to provide an effective means of epiphyseodesis. There was little or no inhibition of epiphyseal growth when care was taken to avoid major trauma during insertion. The wires either separated or the epiphysis continued to grow, leaving the crossed wires behind in the metaphysis (Fig. 7). Transepiphyseal bone condensation was often noted along the line of the wires.

Localized central epiphyseodeses resulted from drilling or curetting various amounts

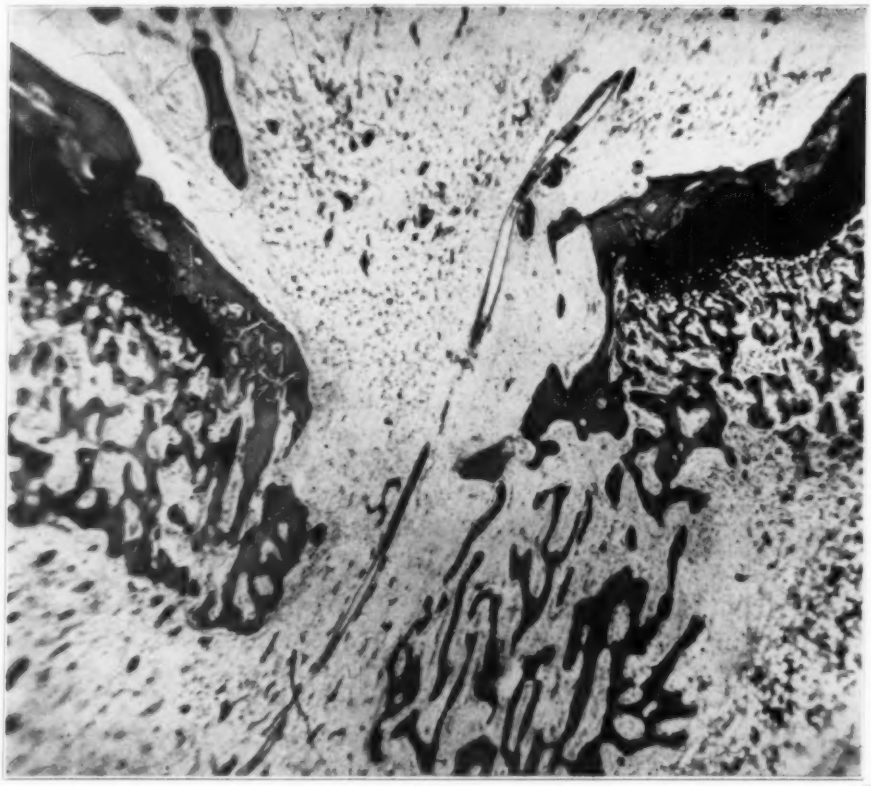

FIG. 9

Histological section six weeks postoperatively, demonstrating the effect of drilling the central portion of an upper tibial epiphysis in a rabbit. Healing has taken place by bone formation across the epiphyseal defect rather than by epiphyseal cartilage proliferation. The bone plug which formed was similar to that in the track of transepiphyseal wires (Fig. 6-B), and continuity between the epiphysis and metaphysis has been remodelled with marrow. There is a locally deforming "dip" in the epiphyseal plate, with pressure effects upon the cartilage cells similar to those noted in the control experiments, in which epiphyseodesis was created by curetting the medial epiphyseal plate (hematoxylin and eosin, × 60).

of the epiphyseal plate through the intramedullary route in a manner similar to the experiments of Ford and Key. Centralized injuries slowed growth but did not cause gross epiphyseal deformity, because concentric growth was uninterrupted in the unimpaired peripheral portion of the epiphyseal plate. However, when these larger defects were eccentric, eccentric epiphyseodeses occurred, and gross epiphyseal deformities resulted (Figs. 8-A and 8-B).

Seen microscopically, the curetted or drilled defect in the rabbits was never repaired by proliferation of epiphyseal cartilage cells, but rather was repaired by bone. At the end of six weeks, remodeling of the transepiphyseal bone plug occurred, so that direct vascular and marrow continuity existed between the epiphysis and the diaphysis, with a localized deformity or "dip" in the epiphyseal plate (Fig. 9). Local pressure effects were noted upon the epiphyseal plate, similar to those existing under a staple or near the areas of epiphyseodesis in the controls of the staple experiments.

SUMMARY AND CONCLUSIONS

This experimental study describes the mechanism of epiphyseal growth inhibition

and eventual epiphyseodesis under staples in rabbits. The effect of stapling is a direct pressure inhibition of the proliferating stage of epiphyseal growth. The cartilage cells of the epiphyseal plate, however, continue their maturation so that the hypertrophic cells degenerate, the palisading cells hypertrophy and eventually degenerate, and finally the proliferating and resting cells pass through a similar sequence. The metaphyseal vascular channels, with the accompanying osteoblasts, invade each successively degenerating group of cartilage cells, thus gradually thinning the epiphyseal plate until eventual epiphyseodesis occurs.

Three histological changes are visible roentgenographically: (1) disappearance of the fine metaphyseal trabeculae, (2) the formation of a dense layer of subepiphyseal bone, and eventually, (3) thinning of the epiphyseal plate. It is suggested that roentgenograms of stapled epiphyses in which growth has not resumed after the staple was removed be restudied to determine their value clinically as warning signs of premature closure of the epiphyseal plate under a staple.

In the transepiphyseal wire experiments it was noted that when a wire traversed the epiphyseal plate there was no interference with longitudinal growth. As the epiphysis grew beyond the wire, the transepiphyseal defect made by the wire was replaced by bone; the epiphyseal defect showed no signs of being replaced by epiphyseal cartilage cells. The degree of the deformity depended upon the location of the epiphyseodesis and its extent. This is demonstrated by the production of eccentric epiphyseodesis and deformity by eccentric curetting of the plate through the intramedullary canal of the tibia. It is suggested, therefore, that when transepiphyseal wires are used clinically they be of small caliber and be placed centrally.

Crossed wires were not an effective means of epiphyseodesis.

It should be emphasized that the results discussed are experimental, and that the studies were performed on rabbits. Since there is great similarity between these experimental observations and many clinical experiences, some of the observations may be of value in throwing light on the problem of epiphyseal growth arrest and deformities due to abnormal epiphyseal plate growth.

NOTE: The author expresses his thanks to Dr. Robert K. Lippman and to Dr. Paul Klemperer for their support of this work, and to Mrs. Sarah Spector for her technical assistance.

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DISCUSSION

Dr. Charles N. Pease, Chicago, Illinois: I want to emphasize that the epiphyseal plate is extremely sensitive to injury and repairs itself poorly. Roentgenograms of epiphyseal plates in rabbits show the warning signs of sclerosis which are associated with thinning of the cartilage; but in the child, long before this happens, the point of no return has been reached. This fact is demonstrated by the number of patients admitted to the Children's Memorial Hospital who have had stapling done elsewhere. There is a child, now thirteen, who had a normal functioning, sound limb at the age of ten when staples were inserted accurately and correctly; at the present time the sound limb is not only shorter than the paralytic one, but there is also a deformity of the tibia and internal derangement of the knee joint.

In cases in which epiphyseal arrest is indicated in very young children I prefer to delay this operation until the child is older, and to use the definitive method of Phemister.

Dr. Robert H. Cassidy, Milwaukee, Wisconsin: Dr. Siffert suggests that thinning of the epiphyseal plate is a warning sign of impending closure. He would like to determine at what point the process of growth is still reversible.

In children, as in rabbits, stapling compresses the epiphyseal plate. Thinning occurs rapidly if the child is in a growth spurt; less rapidly if he is not.

(Slides were shown of a boy whose right distal femoral epiphysis had been stapled for twenty months.) The epiphyseal plate was thin. The removal of staples was a stimulus to temporary accelerated growth which lasted from two to three months; thereafter growth continued at the same rate as the normal side.

(Slides were shown revealing the progress of a patient whose distal femoral epiphysis had been stapled two years before.) The staples were more delicate than those now in use, but they have been efficient. The epiphyseal plate was thin when contrasted with the tibial epiphyseal plate. Two months after the removal of the staples the epiphyseal plate had expanded to a much greater width than the tibial epiphyseal plate.

(A third set of slides showed a tibial epiphysis which had been stapled for three years.) The epiphyseal plate was scarcely visible. The fibular epiphysis had been curetted. Three months after the removal of the staples the tibial plate had greatly expanded.

Stapling should seldom be done in children under the age of eight because of the immaturity of the epiphysis. In children under twelve years of age, staples have been left *in situ* for four years; normal growth resumed when the staples were removed.

A Critical Evaluation of a Method of Epiphyseal Stimulation*

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This report is concerned with the clinical observations and the results obtained in thirty cases in which epiphyseal stimulation was attempted by the use of intramedullary ivory implants in the distal end of the femur and proximal end of the tibia. At least thirty months of observation was possible in all the cases, and in some of the earlier cases follow-up was continued for over three years. At the beginning of this study, it was agreed that in order to obtain accurate evaluation of the results the operation should be performed on a large enough group of patients of different ages to permit quantitative statistical analysis. To permit qualitative appraisal of the method, it was obvious that strict adherence to the established technique must be maintained in every case. It was arbitrarily agreed that thirty cases would be a sufficiently large number to permit adequate analysis of the study. The cases were carefully selected on the basis of the age of the patient, the cause of the inequality of length, and the amount of shortening. It was obvious that a child eight years or older with a shortening of one and one-half inches or greater could not be expected to materially benefit from such a procedure. It was further agreed prior to the beginning of this study that each patient must be followed for at least two years and that during this period no elective operative procedure should be done on either of the patient's lower extremities. The latter requirement, the authors felt, was essential in order to permit an honest appraisal of the method without the necessity of allowing for variables introduced by other operative procedures.

In the past, many methods of stimulation have been tried, both in animal experimentation and in brief clinical studies. Of the many animal experiments that have been done, the work of Trueta appears to have produced the most sound scientific conclusions. He emphasized that to obtain epiphyseal stimulation, the intramedullary circulation must be so altered that an increased blood flow is produced in and about the metaphyseal-epiphyseal junction. Impressed by his experiments, the authors elected to use a method which they felt would produce blockage of the intramedullary circulation while at the same time providing an irritative foreign-body reaction which would further increase the blood flow in the region of the epiphyseal plate. This, they felt, could be accomplished by the use of small ivory chips placed within the medullary canal, proximal to the distal femoral epiphysis and distal to the proximal tibial epiphysis.

OPERATIVE TECHNIQUE

The following operative technique was used in all thirty cases, strict adherence to all details being maintained in each instance. Under high thigh tourniquet control, the distal third of the femur was exposed through an anterolateral incision. The periosteum was incised longitudinally and stripped for a distance of two inches. An oblong window measuring one inch by one-half inch was then removed from the anterior surface of the femur, just proximal to the flare of the femoral condyles (Fig. 1). The medullary canal in this area was thoroughly curetted, the contents were removed, and the cavity created was tightly packed with small chips of ivory obtained from discarded cue balls. The

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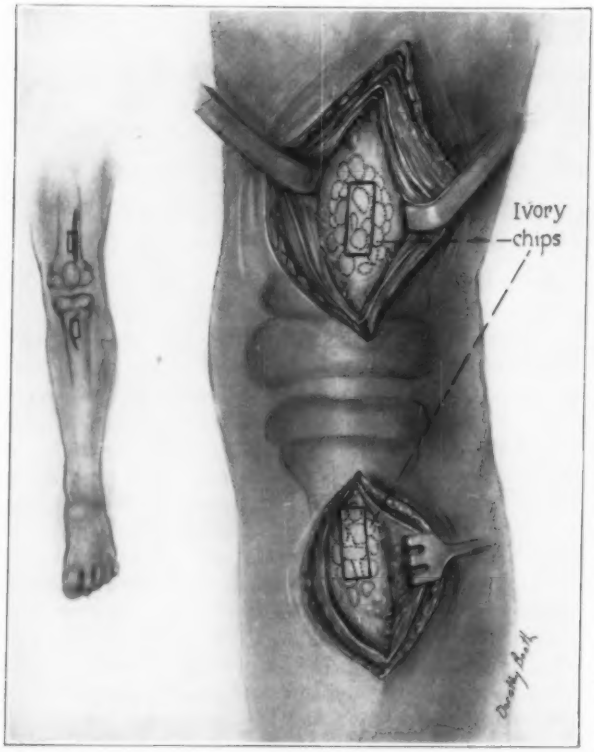

FIG. 1

fenestration was replaced, and the wound closed in layers. The upper third of the tibia was treated in a similar manner, the bone being exposed through a curved anteromedial incision. A cylinder cast was applied, and the patient was permitted ambulation with weight-bearing after the postoperative discomfort and oedema had subsided. Although it is commonly believed that non-weight-bearing is desirable in order to produce a condition of passive hyperaemia, the authors feel that ambulation with weight-bearing is more physiologically sound in that it restores a normal or increased blood flow to the involved epiphyses.

In reviewing the literature published on this subject [1-28], the authors were impressed with the fact that in many reports the conclusions were based on methods of limb-length measurement which were subject to a large element of unavoidable human error. They felt that it was essential to use a method of limb-length measurement which would accurately demonstrate the rate of growth of both the femur and tibia of the short extremity as well as of the opposite extremity. In such a way, any increase in growth of the short femur and tibia could be compared with that of the opposite femur and tibia and, at the same time, the rate of growth of the entire extremity could be measured. In their previous clinical studies on epiphyseal stapling, they had used a method of roentgenographic limb-length measurement which had proved to be statistically accurate within a margin of error of ± 1 per cent (Figs. 2 and 3).

OBSERVED RESULTS OF STUDY

Each patient in this series has been followed closely for a minimum of two years, with clinical and roentgenographic measurements of limb length being made at three-month intervals. The authors were interested in learning not only what increased increment of growth would be produced by the ivory implants, but also over what period of time the stimulating effect lasted. In several of the cases, there were available roentgenograms made during the year prior to the stimulation procedure. These roentgenograms furnished an index of the rate of growth of the good and bad limbs prior to operation, and in this way, a comparison of the rate of growth prior to and following operation was possible. A large amount of statistical information was obtained by the use of these roentgenograms. The results obtained by the stimulating procedure are given in Table III.

Within a year after the start of this study, it was becoming increasingly apparent that the authors' anticipations as to increased growth were not being substantiated.

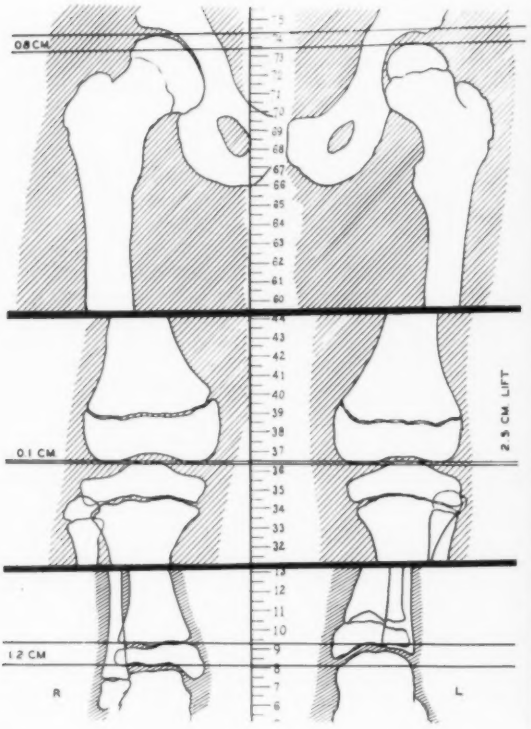

FIG. 2

FIG. 3

An increment in growth was observed in the large majority of cases, but the amount obtained was very small, and the increase occurred only during the first six months following stimulation. Very little increased growth was observed after six months, no growth increment was observable after nine months. Furthermore there was no reason to anticipate any further increase in growth in the future. Contrary to the results in some previous investigations on this subject, there was no retardation of growth in any of the cases, although in four of the cases, no increase in the growth of the femur and tibia as a result of the operation could be demonstrated during the period of observation. It was interesting that all of the patients with shortening secondary to poliomyelitis obtained some increase in the rate of growth. It was also observed that the amount of increased growth was greatest in patients with severe paralysis of the short extremity.

The two patients in whom an increase of three-quarters of an inch was obtained both had totally flail extremities. One was a four-year-old boy with a right limb that was totally flail as a result of an attack of poliomyelitis three years previously. Prior to the stimulation, this limb was one and one-half inches shorter than the other. The increase of three-quarters of an inch that was gained by the procedure was later lost, and when the boy was six and a half years old, the right limb, which was again one and a half inches shorter than the other, was restimulated. At this time it was hoped to at least keep the discrepancy in length from becoming greater before an arresting or shortening operation could be done on the good limb. The boy is now seven, however, and the discrepancy has increased to two and a quarter inches.

The second patient in whom an increase in length of three-quarters of an inch was obtained was a four-year-old boy with a left limb that was totally flail as a result of

TABLE I

ETIOLOGY OF LOWER-EXTREMITY SHORTENING

	Number of Patients
Poliomyelitis	24
Congenital Shortening	3
Congenital Dislocation of Hip	2
Congenital Hemiatrophy	1
Total	30

TABLE II

BONE AGE OF PATIENT AT TIME OF STIMULATION *

Age	Number of Patients
3	1
4	5
5	7
6	7
7	6
8	4
Total	30

* In the majority of cases, roentgenograms of the wrist were used to determine bone age.

poliomyelitis. Prior to the procedure the shortening was one and three-quarters inches. During the nine months following the procedure, there was an increase in length of between three-quarters of an inch and an inch, but three years later, the discrepancy had reverted to one and a half inches.

In these two cases, the discrepancy in length was decreased during the year following surgery, which is confirmatory evidence that the ivory implants did cause an increased rate of growth for at least a short period of time. In the series as a whole there appeared to be no significant differences in the amount of growth obtained in patients of different age levels.

COMPLICATIONS

No postoperative infections and no unusual complications resulting from the operative procedure itself were noted. All wounds healed *per primam*. Two fractures of the femur at the site of the fenestration occurred. One was a transverse fracture without displacement which occurred when the patient fell out of bed four weeks following surgery. The other occurred six months following surgery, and was the result of a fall from a bicycle. Both fractures healed without difficulty.

In these cases, it was not possible to accurately evaluate the results of the stimulating procedures. In the first case, the child did show a gain of a quarter of an inch, but whether this gain was the result of the stimulating procedure or of the fracture could not be determined. In the second case, the fracture was treated elsewhere. When the child was again seen by the authors, there was at least a half inch of overriding of the fragments; and therefore, in this case, as in the first, it was impossible to accurately evaluate the effectiveness of the procedure.

CONCLUSIONS

On the basis of the results obtained by this method of epiphyseal stimulation, it is apparent that while some increase in growth was obtained in twenty-six of the thirty

TABLE III

TOTAL INCREASE IN GROWTH

Gain in Inches	Number of Cases
1/8	10
1/4	11
1/2	3
3/4	1
1	1
Total	26

patients, the amount of this increased growth was not sufficient to justify the procedure. However, while it is true that in 70 per cent of the cases, the maximum gain was only one-eighth to one-quarter of an inch, it is also worthy of note that many of the patients were below the age at which a limb-shortening or epiphyseal-arrest procedure could be done. Furthermore, although the gain was negligible, the stimulating procedure did prevent the inequality in length from becoming greater and in several instances it reduced the inequality to a small amount. For this reason the authors feel that this procedure has some merit in a few isolated instances, such as in a child below the age of six with a discrepancy of one and one-half inches or more and with a flail extremity secondary to poliomyelitis. According to the authors' observations, this method of epiphyseal stimulation very possibly will prevent the discrepancy from becoming greater before such time as a growth-arrest or limb-shortening procedure might be indicated. They also believe that in a child with a discrepancy of one inch or more who had to undergo surgical relaxation of a tight iliotibial band, a stimulating procedure can be carried out through the same operative incision with little additional trauma or operative time.

This study has been a disappointment for the results have demonstrated that the use of intramedullary ivory implants in the distal end of the femur and proximal end of the tibia will not produce a sufficient increase in growth to justify the procedure. The authors have been stimulated themselves, however, to further study this problem in the hopes of finding a method of growth stimulation which will have sound clinical application.

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DISCUSSION

Dr. Robert H. Cassidy, Milwaukee, Wisconsin: The paper presented by Dr. Carpenter and Dr. Dalton describes a type of epiphyseal stimulation that we have used in over sixty cases. Our conclusions are similar to theirs.

The growth that has occurred as a result of this procedure has been unpredictable. While the procedure

has not consistently produced significant lengthening, it has frequently prevented the inequality in limb length from becoming greater.

If the stimulation is carried out during a period when little growth is occurring, the results are likely to be disappointing. If it is done during a period of rapid growth, better results can be expected.

Early in our series we decided that the procedure, as described by Dr. Carpenter and Dr. Dalton, was not justified if used alone. Therefore, we used it at every opportunity in combination with other procedures, such as fasciotomy of the tight iliotibial band or removal of bone for use in Grice's subtalar extra-articular arthrodesis. Such procedures may be done several years before one can consider doing stapling of the epiphysis on the long extremity.

In our experience the effect of the stimulation lasts from six to nine months. It may be repeated as often as is expedient.

We have had more complications than did the authors. The most frequent complication has been fracture of either the femur or tibia through the site of stimulation. Although temporarily disabling, this complication further stimulates epiphyseal growth.

A surprising but frequent finding is that the growth of an epiphysis that is remote from the site of fracture on surgical stimulation is relatively more accelerated than that of an epiphysis that is near this site. This fact can be determined only by the preliminary bilateral insertion of markers in the bones to be studied.

A frequent complication of stimulation of the distal end of the femur is flexion deformity of the knee. In some cases this has necessitated a supracondylar osteotomy, a procedure which further stimulates growth. In patients who back knee, this sequel justifies the use of the stimulation operation.

We are sufficiently satisfied with this type of procedure to continue its use.

Dr. Charles N. Pease, Chicago, Illinois: Dr. Carpenter and Dr. Dalton have presented a fine paper on the use of ivory to stimulate the longitudinal growth of bones. However, these authors have been somewhat indefinite in evaluating their results. In their conclusions they say that the procedure "has some merits in a few isolated instances", and then go on to state that "this method of epiphyseal stimulation very possibly will prevent the discrepancy from becoming greater before such time as a growth-arrest or limb-shortening procedure might be indicated".

The fact that all their patients, including the one with the poorest result, showed a minimal amount of growth acceleration at least proved one thing; that is, that in no case was there reversion to continuous shortening of the limb. In other words, the process of inhibited growth was reversed.

In our series I placed ivory in the medullary canal, not in order to obliterate the canal, but in order to produce a low-grade inflammatory process. The growth of bone was better in those patients in whom the ivory was partially absorbed than in those in whom there was no disintegration, the foreign-body reaction being greater in the former. In the patients in whom there was no absorption, the medullary canal became filled with compact, relatively avascular cancellous bone; in these patients there was not much acceleration of growth.

It has been my experience that plugging the medullary canal inhibits the vascular supply in the epiphyseal region.

Dr. George H. Millington, my associate, has pointed out that if obliteration of the medullary canal produces increased growth of bone, the tibia in congenital pseudarthrosis should be overgrown; actually, however, the reverse is true.

The first few patients in whom I used ivory showed exceptional growth, but in most of the patients treated later the procedure was not too effective, for the reason explained. I, therefore, returned to using metal. In this procedure a small amount of aluminum mesh was placed in the medullary canal, a stainless-steel mesh was placed subperiosteally almost all the way around the bone, and a screw was then inserted transversely through both cortices in such a way that it made contact with both the aluminum and stainless-steel mesh. This procedure created a difference of potential and produced a local battery-like reaction adjacent to the epiphyseal region.

A case that illustrates the acceleration of growth which may be obtained is that of a six-year-old child who had congenital hypoplasia of the tibia. In April, 1955, the technique described was used. Eight months later there was a gain in length of 1.3 centimeters in the femur and of 0.5 centimeter in the tibia.

Experimental Studies on Epiphyseal Stimulation

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A method of stimulating the growing epiphyses in the long bones of dogs by means of electrolysis has been described in previous publications[5,6]. In these articles it was shown that an increase in the length of the long bones can be obtained by the insertion of dissimilar metals into the metaphysis, the metals being placed as close to the epiphyseal line as possible.

In the experiments being reported here, the authors took dissimilar metals widely separated in the electromotive series and fused them together to form a small "battery". It has been found that when this type of unit is inserted into the body fluids, electrolysis occurs, constituting a form of chronic irritation which stimulates foreign-body reaction[4]. Since low-grade irritants evoke hyperaemia, it was felt that this procedure should produce a local increase in bone growth in accordance with the hypothesis held by H. A. Harris.

This project was first started in 1948. In that same year Chapchal and Zeldenrust reported a similar series of experiments which they had carried out during the last war in occupied Holland. These workers also used dissimilar metals in an attempt to stimulate the growing epiphyses in laboratory animals by means of electrolysis. They did not, however, join the metals together. They believed that their method may have inhibited epiphyseal growth.

The present paper is presented as a follow-up of the authors' previous reports on electrical stimulation as a method of increasing bone length.

MATERIALS AND METHODS

For this work young mongrel dogs between ten and fourteen weeks of age and of varying sizes were used. These animals were sacrificed when they were between three months and four years of age in order that growth studies could be made. Recent work by Schlotthauer and Janes has shown that the femoral and tibial epiphyses in dogs close about ten or eleven months after birth. In the authors' experiments the proximal and distal epiphyses of the tibia were stimulated in either the right or the left leg. In every case the following standard approach was used: an incision two to three centimeters in length was made at each end of the tibia over the medial border and was carried down through the periosteum. Drill holes were then made in the bone to accommodate the electrode. The site of insertion was on the metaphyseal side of the epiphyses as close to the epiphyseal line as possible. With growth of the bone, however, the area to be stimulated moved away from the unit, and therefore in another series of dogs the electrode was inserted into the center of the epiphysis itself. In one group of animals osteotomy of the fibula was done in order to determine if this unstimulated bone has a restraining influence on the growth of the tibia.

Another group of animals was used as controls. In these dogs the incisions and drilling were carried out as in the experimental animals, but no metals were inserted. The purpose of this study was to demonstrate the effects of operative trauma alone. Osteotomy of the fibula was also carried out in some of the animals of this group.

It has already been shown[5,6] that the metals must be in contact with each other if they are to function well as a battery. The first dogs experimented upon in the authors' previous series served as another group of control animals. In those dogs the metals had been inserted in the metaphysis but had not been joined. An increase in length of four

FIG. 1

Roentgenogram of tibiae from dog A5 (from the authors' original series of experiments). Measurements made on the roentgenogram showed that an increase in length of four millimeters had occurred. In this dog the metals were touching. Note the widening of the shaft and the increased density of the bone in the area surrounding the electrode.

millimeters had resulted in one animal only (Fig. 1), and in that animal the metals had been in physical contact with each other.

Intravenous barbiturate anaesthesia was employed in all the animals and intramuscular injections of penicillin were given after the operation as a routine measure. The dogs were fed a standard prepared dog food and were kept on a farm in the country until the time of sacrifice. They were not kept in cages but were allowed to run freely in large enclosures. They all received antidistemper inoculations prior to surgery.

After the animals had been sacrificed, a standard roentgenographic procedure was used to measure the lengths of the tibiae. It was felt that this method would be more accurate than direct measurement. The bones were placed on their posterior surfaces on the film, the tube being placed a standard fixed distance of twenty-six inches away from the bones. All measurements were made on anteroposterior roentgenograms and the distance measured was the distance from the tip of the medial malleolus to a fixed point on the medial articular surface of the proximal end of the tibia.

Various combinations of metals were employed, including copper, iron, aluminum, steel, brass, zinc, nickel, silver, and constantan. The "electrodes" consisted of (1) wires which were separate but in contact with each other in the bone, (2) wires twisted on each other, (3) screws composed of two different metals, (4) cores surrounded by a coil of a dissimilar metal, and (5) plates of two different metals fused together. These electrodes were placed in a saline medium and were tested with an ammeter prior to their insertion into the animals. This was done in order to ensure that the metals were not inert and that electrolysis would take place. Some of the units employed in this experiment are shown in Figure 2.

In a number of adult mongrel dogs which had been sacrificed in experiments unrelated to bone work (that is, in cardiac and gastro-intestinal experiments) the tibiae were removed and measured. This procedure was done in order to determine how much the tibiae of a normal dog differ in length.

Finally, because of the encouraging results which had previously been obtained in human patients [5,6], a series of children in whom limb-length discrepancies were present were subjected to epiphyseal stimulation. These children were selected mainly from patients at the Orthopaedic Clinic of the Children's Memorial Hospital in Montreal.

RESULTS

One hundred and forty operative procedures were performed on 129 dogs. The mor-

TABLE I

MORTALITY RATE

Series	No. of Dogs	Dogs Surviving More Than One Month	Postoperative Deaths (*No. of Cases*)	Postoperative Deaths (*Per cent*)
A	11	7	4	36
B	4	1	3	75
C	14	10	4	29
Ta	10	7	3	30
Tb	67	33	34	50
E	23	15	8	33
Total	129	73	56	43

tality rate was 43 per cent, which left seventy-three dogs which could be studied (Table I). This high mortality is explained by the large number of postoperative upper-respiratory infections which occurred in these young dogs.

The measurements of the tibiae of the twenty "normal" adult mongrel dogs of varying sizes showed that in 40 per cent of these dogs differences in length were present. In only three were the discrepancies of any real significance (that is, more than one millimeter), but the measurements did show that the tibiae of a normal dog do vary in length.

The control dogs which were subjected to the operative procedure but in which no electrodes were inserted showed no significant increase in leg length. In some of these dogs osteotomy of the fibula had been performed on the ipsilateral side.

The results found in the experimental animals in which the electrodes were inserted in the metaphyses are shown in Table II. As noted previously, all the metals had been tested with the ammeter prior to insertion. The figures obtained in these tests are not given here as the amount of current which was found varied according to the size of the surface area of the metals and according to how far apart the metals were in the electromotive series. The authors made no attempt to measure with any degree of accuracy the relative strengths of the different combinations of metals. Suffice it to say that all the

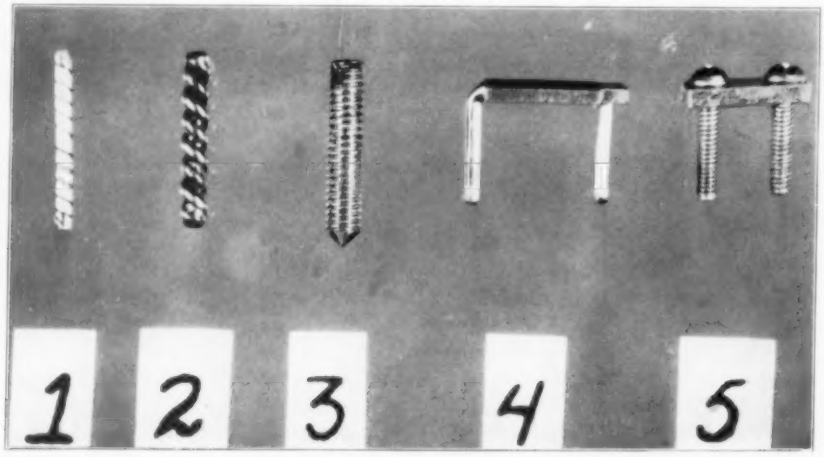

FIG. 2

Some of the different types of electrodes used in this experiment.

TABLE II

EXPERIMENTAL ANIMALS IN WHICH ELECTRODES WERE INSERTED IN THE PROXIMAL AND DISTAL PORTIONS OF THE TIBIAL METAPHYSES

Dog Number	Months Postoperative	Metals Used*	Discrepancy in Length of Experimental Leg (*Centimeters*)	Remarks
B 3	48	Brass and steel	−0.1	
C 2	3	Ni and const	+0.2	
C 3	3	Ni and const	+0.2	
C 5	39	Fe and steel	+0.3	
C 6	37	Fe and steel	−0.1	
C 7	3	Fe and steel	+0.1	
C 8	3	Fe and steel	0	
C 9	3	Cu and const	+0.4	
C 10	2	Cu and const	0	
C 11	20	Cu and const	0	
C 13	3	Brass and steel	+0.2	
C 14	3	Cu and const	+0.2	
T 3	12	Cu and const	+0.1	
T 4	11	Cu and Zn	+0.2	
T 8	10	Cu and const	+0.4	
T 10	9	Cu and const	−0.7	Unit through epiphysis
T 11	7	Cu and const	−0.5	Unit through epiphysis
T 13	15	Cu and steel	−0.2	Unit through distal epiphysis
T 15	20	Cu and steel	+0.1	
T 16	14	Cu and steel	+0.1	
T 18	16	Cu and steel	−0.3	Unit through epiphysis
T 19	17	Cu and steel	−0.6	Unit through epiphysis
T 30	17	Cu and steel	−0.2	
T 31	14	Cu and steel	−0.4	
T 35	14	Cu and steel	−0.1	
T 36	15	Cu and steel	−0.2	Lower epiphysis damaged
T 37	16	Cu and steel	−0.2	Lower epiphysis damaged
T 38	3	Cu and steel	0	
T 43	13	Ni and Ag	0	
T 45	16	Cu and Al	−0.3	Unit through epiphysis
T 46	15	Cu and Al	−0.1	
T 49	13	Fe and Cu	0	
T 50	13	Fe and Cu	−0.5	Unit through epiphysis
T 54	8	Al and Cu	−0.7	Unit through epiphysis
T 56	12	Al and Cu	−0.5	Unit lying close to distal epiphysis
T 60	13	Fe and Cu	0	Unit through proximal epiphysis
T 63	13	Fe and Cu	−0.3	
E 4	5	Cu and const	0	Osteotomy not united
E 5	5	Cu and const	+0.1	
E 7	5	Brass and const	0	Osteotomy united
E 8	5	Brass and const	−0.2	Unit through lower epiphysis
E 9	1	Brass and const	−0.4	Lower unit through epiphysis; premature closure
E 10	4	Cu and const	+0.1	Infection upper unit; lower unit extruded
E 16	3	Cu and const	+0.3	
E 17**	3	Cu and const	+0.5	Osteotomy not united
E 18**	3	Brass and const	+0.3	Lower unit extruded; osteotomy united

* *Cu*, copper; *Ni*, nickel; *Fe*, iron; *Zn*, zinc; *Al*, aluminum; *Const*, constantan; *Ag*, silver.
** Fibular osteotomy performed same side.

FIG. 3

FIG. 4

Fig. 3: Roentgenogram of tibiae from dog C9. This roentgenogram was made at the time of autopsy, three months after the operation. Note the dense bone which surrounds the clear area in the immediate vicinity of the unit. An increase of four millimeters had occurred in this animal, in which electrodes in intimate contact had been inserted.

Fig. 4: Roentgenogram of tibiae from dog E17. This roentgenogram was made at the time of autopsy, three months after operation. Note the hypertrophy of the bone next to the plates and the density of the surrounding bone. The osteotomy fragments have not united. Measurements made on the roentgenogram showed that there was a growth increment of five millimeters.

metals used were tested and that for all but the plate type the readings were in the neighborhood of ten micro-amperes. For the plate-type unit, which was used in the last group of animals, the readings were doubled (Figs. 2 and 4).

At autopsy the unit was found in the bone, either fixed fairly tightly in the surrounding bone or lying in a cavity, three to five millimeters in diameter, which was filled with granulation tissue. The surrounding tissues often showed some staining as a result of dissolution of the metals, and there was generally a dulling of the original shininess of the wires. In some of the animals in which copper was used, little of this metal remained. On the roentgenograms the site of insertion was visible as a clear area surrounding the metals, with a peripheral zone of sclerotic bone. These features are illustrated by the roentgenogram of dog C9, in which an increment of four millimeters was obtained (Fig. 3).

In some of the bones, examined at varying times after the operation, there was a widening of the shaft which extended from the electrode to the epiphysis. This widening occurred in the dogs in which there was also an increase in the length of the bones. In the group of animals in which a large plate-type unit was employed, the widening was particularly noticeable, and in addition there was some growth of the bone over the edges of the unit (Fig. 4).

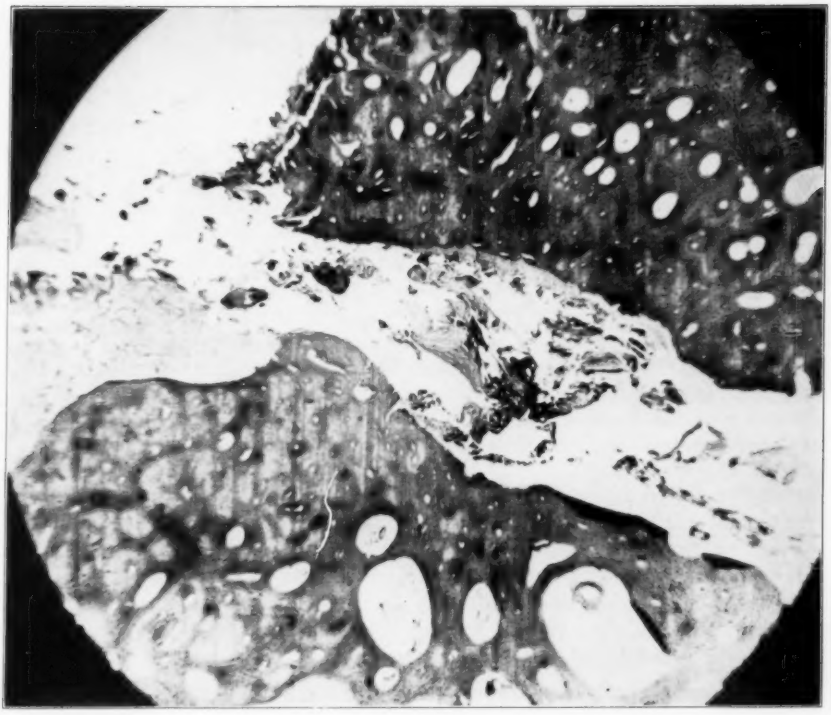

FIG. 5

Photomicrograph (× 8) of bone taken from near the entrance to the electrode tunnel in dog T8. Direct measurements revealed a growth increment of four millimeters.

In a number of cases microscopic sections were made from material taken from the area of the proximal electrode tunnel. These sections showed evidence of the occurrence of some reaction in the immediate area of the unit. In the dog in which copper and constantan were used (dog T8), there was a great increase in the density of the bone with little trabeculation. The bone was rather avascular and there was no hyperaemia of the surrounding tissues. Furthermore, there was no marked foreign-body reaction and no giant cells were noted. The marrow spaces showed normal blood vessels and the spaces between the trabeculations were small. A photomicrograph of a section made from dog T8 is shown in Figure 5. Direct measurements revealed that the growth increment in this dog was 0.4 centimeter.

Some of the units were removed and tested after the animal had been sacrificed. A current of about five micro-amperes was produced in each. This procedure could not be done in every case, as often very little of the metals remained or else what did remain disintegrated on removal. Table II shows that shortening of the tibia occurred when the insertion of the electrode caused damage to the epiphysis. In most of the animals with epiphyseal damage a high-speed electrical drill had been used. In many animals the unit traversed the epiphyseal line.

In order to test the ability of the metals to produce a current within the bones of an animal, another experiment was devised. In this experiment, copper and steel wires were inserted, about one inch apart, into the metaphysis of the tibia of a dog so as to extend across the bone from cortex to cortex. (These wires had been tested for electrolysis prior to insertion.) An ammeter was then connected to the ends of the wires which had been

TABLE III

EXPERIMENTAL ANIMALS IN WHICH THE ELECTRODE WAS INSERTED INTO THE EPIPHYSIS

Dog Number	Months Postoperative	Metals Used	Discrepancy in Length of Experimental Leg (*Centimeters*)	Remarks
T 68	11	Cu and Ag	0	
T 70	11	Cu and Ag	−0.2	
T 85	10	Cu and Ag	−0.6	Unit through epiphyseal line
T 86	10	Cu and Ag	−0.2	Unit through epiphyseal line
T 87	11	Cu and Ag	−0.2	Unit through epiphyseal line
T 88	10	Cu and const	+0.1	
T 91	9	Cu and const	0	
T 94	9	Cu and const	0	

NOTE: In this group one unit was inserted into the proximal growth center of the tibia.

left protruding through the skin on one side. A current of about twenty-five microamperes was recorded. Following this procedure the wires were joined on the skin surface and the leg was immobilized in plaster in order that the involved area might be protected. A window was cut in the cast over the involved area and readings were taken during the next two weeks by inserting an ammeter into the circuit. In each instance a similar reading was obtained. This experiment could only be carried on for about two weeks, for pin-tract infections developed at the sites of the wires. The current produced by the wires when they were placed in a saline medium after removal was about the same as the current produced when they were in the dog.

There was no evidence of wound sepsis in any of the dogs except one. In this dog, the plate electrode which was used was disproportionately large and caused pressure on the overlying skin. This area of skin sloughed and infection subsequently developed.

In one series of animals, the unit was inserted into the epiphysis itself in order to prevent the epiphyseal line from growing away from the stimulating agent. The results obtained in these animals are shown in Table III. No lengthening was produced, and the shortening that resulted is explained by the fact that in most instances the unit traversed the epiphyseal line. This was found rather difficult to prevent because of the small size of the tibial growth center in a puppy.

Finally, a group of children in whom various discrepancies in bone length were present were subjected to epiphyseal stimulation. It was felt that this attempt should be made because of the encouraging results that had been previously obtained in human patients [5,6]. In only two children was the discrepancy decreased, and it is felt that the changes in these children were of no significance. In none of the children did any ill effects occur as a result of the procedures.

COMMENTS

From these experiments it would appear that electrolysis in the area of the growing epiphysis in experimental animals produces lengthening of the bone in many instances. Electrolysis is not, however, a reliable or a predictable means of stimulating longitudinal growth. In the group of animals in which the greatest lengthening was obtained, the mass of the metals used was larger than that of the metals used in any of the other series of animals. The greater growth which occurred in these animals could, therefore, be explained by the larger surface area of the unit and by the larger amount of current which resulted. In this group, the operative trauma was undoubtedly greater than that in any

other group, for the insertion of the larger unit involved incising and stripping of the periosteum for two to three centimeters. Furthermore, after insertion of the unit, the periosteum could not be closed completely. In the control group, although the same exposure was used, the periosteum could be returned to its normal position. In this group lengthening was noted in only two animals and was of a significant amount in only one. In the control animals in which the unjoined metals were used, there was no growth increment, a fact which would tend to rule out foreign-body or corrosion factors as the stimulating agents. It is felt that the length increments which occurred in this study might not have been permanent. On careful inspection of the figures, it will be seen that the animals in which an increase in growth was noted were the ones which were sacrificed one to four months after operation. This was also the case in the original experiments [5,6]. The findings in the human patients in this connection are not conclusive, for, although periodic follow-up roentgenograms were made, no real growth increment was noted at any time. Perhaps the mass of the metals used in these patients was too small, and it can be argued that the epiphyses which were stimulated were abnormal, their growth having been slowed by disease.

It would appear that the answer to the problem of obtaining sustained growth might be the insertion of larger electrodes into the metaphysis. If this is done in the period prior to closure of the epiphysis, a sustained growth increase might be obtained, for it appears that electrolysis, *per se*, has a definite stimulating effect on the epiphysis.

SUMMARY AND CONCLUSIONS

1. When two dissimilar metals were joined together and inserted into the metaphyses of the long bones of puppies, ten to fourteen weeks old, as close to the epiphyseal line as possible, stimulation of longitudinal growth was sometimes obtained. This growth was apparently not sustained, however, for it was found only in animals which were sacrificed from one to four months after the operation. The amount of growth obtained varied from one to five millimeters.

2. The animals in which an increase was obtained constituted 36 per cent of all the experimental animals, and, if the animals in which epiphyseal damage occurred at the time of insertion are excluded, the percentage rises to 52. Of the dogs in which the larger plate-type electrodes were inserted without resulting epiphyseal damage, 71 per cent showed an increase in length. The most consistent results were obtained with the use of copper and constantan.

3. In some animals the unit was inserted into the growth center itself or into the epiphyseal line. This procedure resulted in shortening of the bone.

4. In one control series of animals the same operation was performed without insertion of the metals. This group showed no *uniform* increase in growth, although in one animal there was a growth increment of three millimeters. In another series of control animals the ununited metals were inserted into the metaphysis; this group also showed no growth stimulation. It has not been shown that operative trauma or metallic corrosion were directly responsible for any increase in length.

5. The performance of a fibular osteotomy had no effect upon growth under the conditions of this experiment. Comparable growth increments were obtained in the animals with and without osteotomy.

6. A series of children were also subjected to this method of epiphyseal stimulation with no appreciable increase of growth noted. Perhaps this negative result was due to the small mass of the metals employed. No ill effects were noted from these procedures in any patient, but further experimental work must be done before this method is again employed in children.

7. It is felt that the increased growth which was obtained in this study was due to electrolytic stimulation, the intensity of this stimulation varying directly with the surface

area of the electrodes employed. No ill effects resulted from the presence of the metals in the dogs, even after four years.

ADDENDUM

Since the completion of this study, the wires were removed from the leg of a sixteen-year-old boy after four years. There had been a growth increment of one-half inch. The wires were found in the same holes and were surrounded by granulation tissue, as were the wires in the experimental animals. There was some staining of the surrounding soft tissues.

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The Arterial Supply of the Adult Humerus *

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The importance of a knowledge of the blood supply of the part the surgeon is to treat needs no emphasizing. This is no less true of the long bones than of the viscera and has prompted some anatomical investigations of special regions in the past. Recently attention has been given to the head of the femur [6, 15, 16] and to the lower end of the femur [10]. The arterial supply of the femoral shaft has been studied by the author [8]. This latter work stimulated the author to a study of the arterial supply of the entire humerus. Local exigencies, however, have limited the material available to adult bones. A future study of the arterial supply of the humerus in children is planned. It is believed that the knowledge derived from these studies will prove valuable to surgeons dealing with injuries and diseases of the humerus.

REVIEW OF PRESENT STATE OF KNOWLEDGE

Most authorities consulted appear to be in agreement that there are two nutrient canals in the humerus which are inclined downward, one on the medial surface and one in the spiral groove, and that the nutrient artery of the head springs from the anterior humeral circumflex artery at the upper end of the bicipital groove. Frazer, however, mentioned no main nutrient artery to the shaft in his description of the humerus; he did mention the capital branches of the ascending branch of the anterior humeral circumflex artery. He stated that the foramina for these vessels are found in the upper part of the bicipital groove.

Johnston and Whillis stated that there is a nutrient foramen on the anteromedial surface of the shaft just below its mid-point. In describing the brachial artery, they stated that the profunda brachii sometimes supplies a nutrient vessel to the humerus in the spiral groove and that the main nutrient vessel springs from the brachial artery itself and enters the shaft below the insertion of the coracobrachialis. The anterior humeral circumflex artery was described as giving off an ascending branch in the bicipital groove to supply the head of the humerus. Goss and Brash were in substantial agreement with the above description. Thorek stated that a nutrient foramen is found near the middle of the medial border of the humerus and that another is found frequently in the spiral groove. No mention of the source of the nutrient arteries was made.

Spalteholz described a large nutrient foramen at the mid-point of the shaft on the medial border. He illustrated both this foramen and a posterior one in the spiral groove at the junction of the upper and middle thirds of the shaft. Spalteholz described the nutrient artery of the humerus as arising from the profunda brachii and only sometimes from the brachial artery or a muscular branch. Sobotta described and illustrated a mid-shaft medial nutrient foramen and said that several small branches of the profunda brachii enter their corresponding foramina. Grant showed a nutrient foramen posteriorly in the spiral groove at the junction of the upper and middle thirds but made no mention of a medial nutrient artery. Lexer and his associates investigated the blood supply of the long bones by means of injection of a mercury and turpentine emulsion and subsequent roentgenograms. They mentioned one nutrient artery of the humerus, without giving further details as to its origin or the site of its foramen.

Anseroff, using metallic mercury, Spalteholz preparations, and roentgenograms in children's and adults' bones, illustrated one main medial and one accessory posterior

* Canadian Department of Veterans Affairs Research Project 3–55.

nutrient artery but made no attempt to describe them further except to state that the nutrient canals are inclined downward.

METHOD AND MATERIAL

As in the study of the blood supply of the femur [8] it was proposed to inject the limbs of cadavera at autopsy and then to remove the bones for roentgenographic study. The arms of routine autopsy subjects were injected via the third part of the subclavian artery. The artery was exposed by careful dissection and an attempt was made not to cut any vessels. If any vessels were cut, allowing the escape of the injection medium, they were clamped. This was done in order to maintain the pressure of the injection. The subclavian artery was tied proximally and a glass canulla was inserted and tied in, pointing distally. A rubber tube was then attached to the canulla and the medium was injected through an ordinary twenty-five cubic centimeter syringe by means of hand pressure. In older subjects with atheromatous vessels more pressure was needed and a ten cubic centimeter syringe was used, as it was found easier to handle. In order to conserve the injection medium, a rubber tourniquet was applied just below the elbow in all cases. In the first nine cases a mixture of barium sulphate and formalin was used, both to inject the vessels and to fix the bones for histological study. This mixture was made of about the consistency of cream. The tendency was, however, to make it too thin for sufficient barium to reach the finer vessels and in later cases the mixture was made thicker.

In the first nine cases, and in number thirty, one arm only was injected. From the tenth to the twenty-ninth cases both arms of each subject were injected. The mixture of barium sulphate and formalin was used in one arm and a mercury-turpentine emulsion in the other. This last medium was used to give a better contrast between the fine intra-osseous vessels and the bone on subsequent roentgenograms. It was necessary to avoid over-emulsification of the mercury. A thick emulsion could not be injected easily as it became of the consistency of clotted cream. Hand-shaking of the mercury with an excess of turpentine for a few minutes was found to be adequate and no mechanical agitation was needed.

No attempt was made to measure the pressure of the injection. In younger subjects, in whom softer vessels made the injection easy, the end point of the injection was the movement of blood up the subclavian veins. This movement occurs when the medium reaches the capillary bed. At this point the injection was discontinued in order to avoid filling the venous system and so confusing the picture in the roentgenograms.

After completion of the injections the bones were removed. The injected vessels were easily followed during the dissection and the source of the main nutrients could be distinguished in most cases. The bones were then stripped of all periosteum and muscles, and the ligaments were removed as far as was practicable. In this way the dense periosteal capillary bed and the vessels of the soft tissues were removed, so that only the injected intra-osseous arteries showed on the roentgenograms. Anteroposterior and lateral roentgenograms of the bones were then made. Suitable bones were sectioned to give further information about the internal architecture of the arteries.

Some of these slices of bone were decalcified in a 10 per cent nitric acid solution so that a clearer picture of the finer vessels could be obtained. The mercury-turpentine emulsion was not affected by the decalcification process. The attempt to examine the bones histologically proved a failure since adequate fixation of the bones was not obtained unless they were cut up at once after removal and put into formalin or another fixative. This proved impracticable since the bones had to be kept intact for several days in case additional x-rays were needed.

In all, thirty adult humeri were injected. These came from subjects in the fourth to the ninth decade. In the older subjects degenerative changes had often narrowed all the vessels of the limb, making the injection difficult and the roentgenograms poor.

FIG. 1 FIG. 2 FIG. 3 FIG. 4

Fig. 1: Roentgenograms of Specimen 12, showing a good mercury emulsion injection, with some pools of mercury at points of rupture of capillaries.
Fig. 2: Roentgenograms of Specimen 15. The mercury emulsion has not reached the lower end of the bone.
Fig. 3: Roentgenograms of Specimen 16. A thicker barium suspension was used in this case. Note the anterior accessory nutrients.
Fig. 4: Roentgenograms of Specimen 17. Note the large medial ascending capital artery.

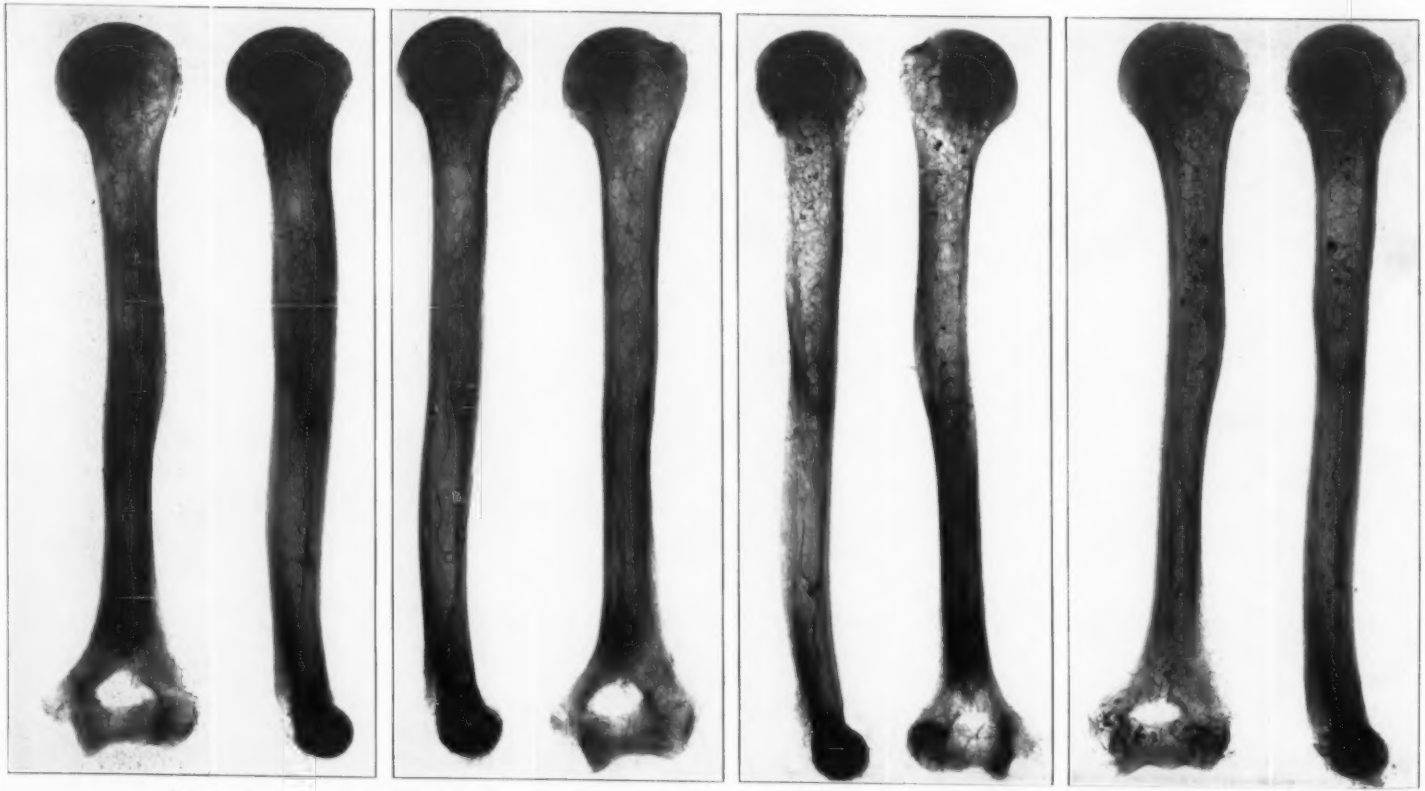

FIG. 5 FIG. 6 FIG. 7 FIG. 8

Fig. 5: Roentgenograms of Specimen 19.
Fig. 6: Roentgenograms of Specimen 21, showing two main nutrient arteries of the shaft.
Fig. 7: Roentgenograms of Specimen 22. An accessory nutrient enters the spiral groove posteriorly.
Fig. 8: Roentgenograms of Specimen 25. Note the arcuate artery of the head.

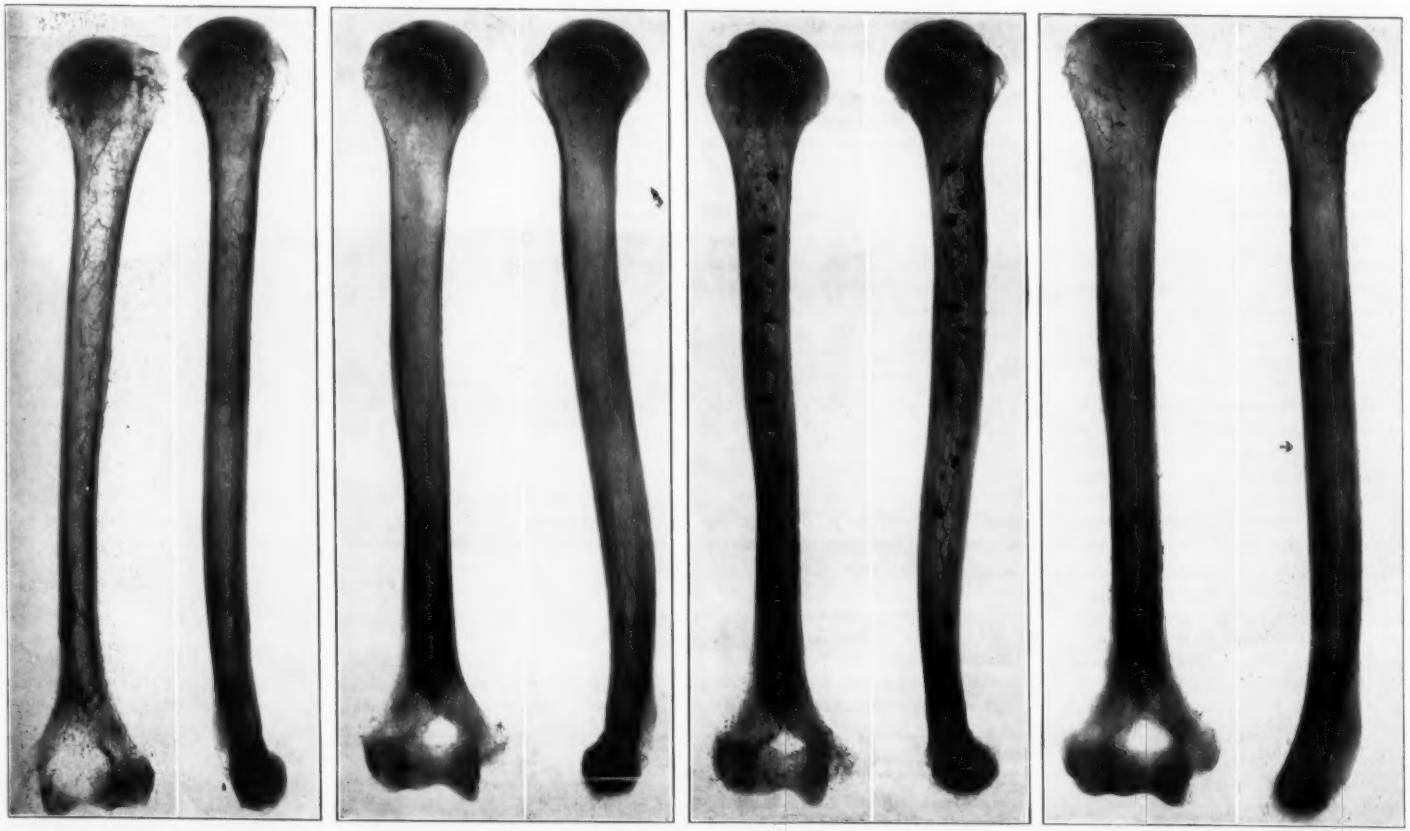

FIG 9 FIG. 10 FIG. 11 FIG. 12

Fig. 9: Roentgenograms of Specimen 27, showing two main nutrient arteries of the shaft.
Fig. 10: Roentgenograms of Specimen 28, showing a good barium injection.
Fig 11: Roentgenograms of Specimen 29. Excessive pressure has ruptured many capillaries, resulting in pools of mercury.
Fig. 12: Roentgenograms of Specimen 30. The main nutrient artery was not filled and was probably blocked. Mercury may be seen in the medullary cavity.

TABLE 1

ANALYSIS OF INJECTED ADULT HUMERI NOT ILLUSTRATED

Specimen No. Injection Material	Result	Main Nutrient Artery of Shaft	Accessory Nutrient Arteries of Shaft	Blood Supply of Humeral Head
1 Barium and formalin	Poor	One entering cortex on anteromedial surface at mid-point of shaft. Cortical canal $1\frac{1}{4}$ inches long.	One descending from lower end of bicipital groove and arising from descending branch of anterior humeral circumflex artery.	A large vessel entering at upper end of bicipital groove, springing from the ascending branch of anterior humeral circumflex. The arcuate artery is not well developed. Small branches enter the head posteromedially and spring from the posterior humeral circumflex.
2 Barium and formalin	Poor	One entering anteromedially at junction of middle and lower thirds.	One small accessory entering anteriorly at junction of middle and upper thirds.	A large anterolateral artery from anterior humeral circumflex artery forming arcuate artery. Several small posteromedial twigs come from the posterior humeral circumflex artery.
3 Barium and formalin	Good	One entering anteromedially at junction of middle and lower thirds with $1\frac{1}{4}$ inches cortical canal.	None seen.	The anterolateral capital nutrient (branch of the ascending branch of the anterior circumflex humeral artery) forms the arcuate artery. Small posteromedial twigs join the arcuate and spring from the posterior circumflex and humeral.
4 Barium and formalin	Poor	One entering anteromedial surface at junction of middle and lower thirds with $1\frac{1}{8}$ inch canal.	One small vessel entering lower end of bicipital groove and descending to shaft.	Small anterolateral and posteromedial arteries with no obvious arcuate artery.
5 Barium and formalin	Poor	One entering anteromedially at junction of middle and lower thirds, with $1\frac{1}{8}$ inch canal.	One anteromedially at junction of middle and upper thirds.	Large anterolateral and small posteromedial arteries with poor penetration of head.
6 Barium and formalin	Fair	One entering anterior surface in the mid-line at junction of middle and lower thirds. Canal 2 inches long.	One on anterior surface at junction of upper and middle thirds, one on anterolateral surface at mid-point of shaft.	Anterolateral artery well marked. Posteromedial artery can just be made out. No true arcuate vessel seen.
7 Barium and formalin	Good	One entering anteromedial surface at junction middle and lower thirds with $1\frac{1}{4}$ inch canal.	One small accessory nutrient in midline anteriorly at junction of upper and middle thirds.	One large anterolateral artery forming an arcuate vessel and one small posterolateral artery.

8 Barium and formalin	Very good	One entering anteromedial surface at junction of middle and lower thirds. Cortical canal 1 1/8 inch long.	Two small arteries entering anteriorly in mid-line at junction of upper and middle thirds.	A large anterolateral artery forms arcuate artery, joined by a posterolateral artery of unknown origin.
9 Barium and formalin	Poor	One entering anteromedial surface at junction of middle and lower thirds. Canal short.	One entering second quarter on outer surface, splitting into ascending and descending branches.	Two anterolateral arteries enter head and pass backward below the obliterated epiphyseal line for 1 inch. Small lateral and posterolateral branches.
10 Barium and formalin	Poor	One entering posteromedial surface at junction of middle and lower thirds with 1 1/2 inch canal.	One descending from lower end of bicipital groove.	Anterolateral and posteromedial nutrient arteries present. No arcuate artery.
11 Mercury and turpentine	Poor	One entering anteromedially at junction of middle and lower thirds. Canal 3/4 inch.	One large, in mid-line anteriorly at junction of upper and middle thirds, ascending and descending branches. One small, 1 inch above, anastomosing superiorly and inferiorly.	One small anterolateral artery.
13 Barium and formalin	Good	One entering medial border at junction of middle and lower thirds, with 1 1/4 inch canal.	One large, entering mid-line posteriorly in spiral groove at lower end of upper third. Three small arteries enter anteriorly in upper third.	A good arcuate system is formed by anterolateral and smaller posteromedial arteries of head.
14 Barium and formalin	Good	One entering anteromedially at junction of middle and lower thirds, with 1 1/4 inch canal.	One small descending from lower end of bicipital groove and one from posteromedial aspect.	A large anterolateral artery forms the arcuate artery and receives contributions from the posteromedial artery.
18 Barium and formalin	Good	One enters medial border at junction of middle and lower thirds with 1/2 inch canal.	One at junction of upper and middle thirds anteromedially. One small artery posteriorly at junction of upper and second quarters of shaft. A third descends from the head.	A large anterolateral artery divides into two: a superior branch to head and an inferior branch to shaft. Some small posteromedial vessels are seen.
20 Barium and formalin	Poor	One medial artery at junction of third and fourth quarters with 1 inch inch canal.	One small artery anteriorly middle of upper third.	Large anterolateral artery forms a low-lying arcuate vessel. Small posterolateral vessels are seen.
23 Barium and formalin	Poor	Anteromedial artery in lower part of middle third with 2-inch canal.	One posteriorly in upper part of middle third.	Large anterolateral and posteromedial arteries with arcuate arrangements.
24 Barium and formalin	Good	One anterior artery in mid-line in lower part of upper half of shaft.	One anterior in mid-line in upper third and one posterior in spiral groove.	Large anterolateral artery forms arcuate artery. Posterolateral lateral arteries.
26 Barium and formalin	Good	One anteromedially at junction of middle and lower thirds, with 1 1/8 inch canal.	One in lower part of upper third in mid-line anteriorly. One descending artery anteromedially.	Large anterolateral artery, posteromedial and medial twigs.

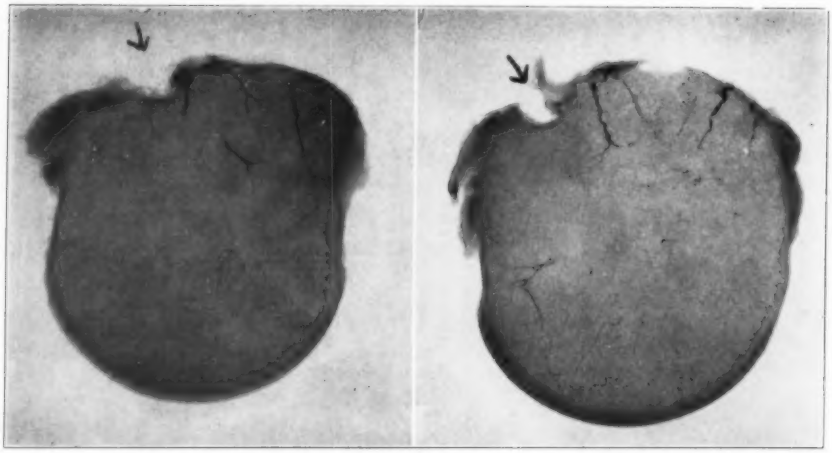

FIG. 13

Roentgenograms, made after decalcification, of one-centimeter horizontal sections from the humeral head of Specimens 8 and 25. Arteries may be seen entering the humeral head by way of the bicipital grooves (arrows) and the greater tuberosities. Barium and formalin injections were used.

RESULTS

Dissection

In twenty cases in which a careful dissection was made the main nutrient artery was found to arise directly from the brachial artery. In three cases a vessel was seen springing from the profunda brachii and immediately entering the bone in the spiral groove posteriorly (Fig. 7).

Injections

The bones injected with barium and formalin did not show as satisfactory a delineation of the intra-osseous arteries as did those injected with the mercury-turpentine emulsion. In thirteen cases the contrast between the barium-filled arteries and the bone on the roentgenograms was not sufficient to reproduce well.

Table I presents an analysis of those roentgenograms not shown in the illustrations. Only the main vessels to the shaft and head of the humerus are mentioned. The term "main nutrient artery of the shaft" was adopted to describe the largest artery. All other sizeable nutrient arteries are termed "accessory nutrient arteries of the shaft". When the pressure of the injection was sufficient to fill smaller vessels in the cortex these vessels are described as "small transcortical arteries or vessels".

Main Nutrient Artery of the Shaft

The main nutrient artery of the shaft was single in twenty-eight cases and double in two cases (Figs. 6 and 9). This artery entered the bone anteromedially in twenty bones, medially in six, anteriorly in five, and posteromedially in one. The point of entry along the length of the shaft was at the junction of the middle and lower thirds or in the lower part of the middle third in twenty-four bones, around the mid-point in four, and at the junction of the third and fourth quarters of the shaft in two bones.

In all cases the course of the artery through the cortex was downward. The length of the intracortical canal varied from one-quarter of an inch to two inches. When the main nutrient artery was single it broke up into ascending and descending branches either on entering the medullary cavity or in the canal. In Specimens 21 and 27 (Figs. 6 and 9)

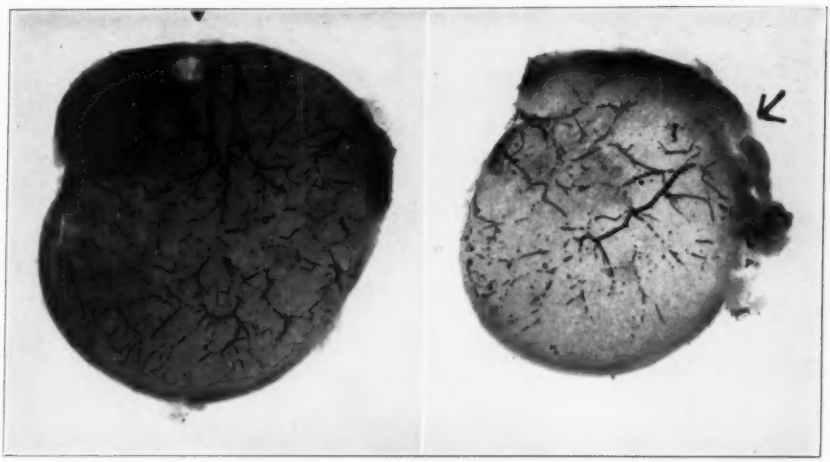

FIG. 14

Roentgenograms, made after decalcification, of one-centimeter horizontal sections from the humeral head of Specimens 19 and 29. The capital nutrient arteries may be seen entering by way of the bicipital grooves (arrows). Mercury and turpentine injections were used.

the division took place outside the bone and each branch had its own canal and nutrient foramen. The superior branch became the ascending artery of the shaft and the inferior branch, the descending artery.

In most cases a peculiar coiled arrangement of the beginning of the ascending branch was noted. The ascending branch was seen to travel up the medullary cavity of the humerus and to anastomose with any accessory nutrient arteries present. It was also seen in some bones to communicate with the periosteal arteries by many small transcortical vessels (Figs. 2, 4, 9, and 11).

The descending branch was usually smaller than the ascending branch. It divided immediately into many fine arteries and continued in the general direction of the nutrient canal (Figs. 4 and 9) to reach the supracondylar and epicondylar regions.

Accessory Nutrient Arteries of the Shaft

These arteries were found in all except the third specimen and varied in number from one to four. They were never as large as the main nutrient and most were very fine. In well injected bones (Figs. 2, 4, 5, and 9) many minute transcortical vessels could be seen but these were considered not to be true nutrient arteries but merely distended small vessels. In seven bones one or several arteries entered the posterior surface in the spiral groove arising from the profunda brachii (Figs. 5 and 7). These vessels were all small and no nutrient foramen was visible on the bone surface.

In nine bones an accessory nutrient vessel entered the upper end of the shaft anterolaterally and descended springing from the descending branch of the anterior humeral circumflex artery (Figs. 1, 3, and 9). In one bone a posteromedial accessory artery descended into the shaft from the region of the posterior humeral circumflex artery (Fig. 8). In only one bone was there a sizeable accessory nutrient vessel entering the lateral surface. It was remarkable that most of the accessory nutrient arteries entered the upper third of the shaft anteriorly or anteromedially. Occasionally there were vessels extending as low as the mid-point of the shaft. No true accessory nutrients were seen between the site of the main nutrient artery and the epicondylar region. In one bone (Fig. 12), although the main nutrient was blocked, the injection medium reached the medulla via the collateral arteries.

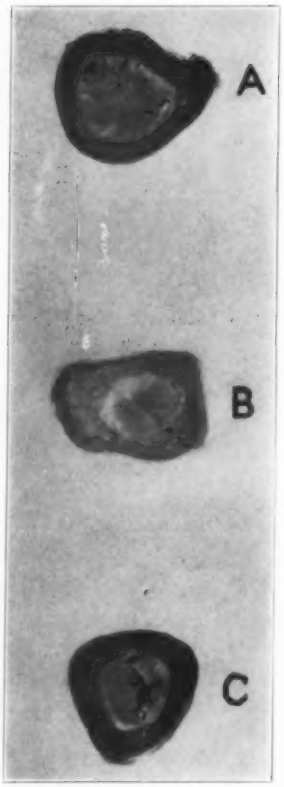

FIG. 15

Fig. 15: Roentgenograms of decalcified cross sections of the shaft of Specimen 13 illustrating the distribution of the arteries in the medullary cavity. *A*, section from the junction of the first and second quarters; *B*, section from the mid-point; and *C*, section from the junction of the third and fourth quarters of the shaft.

Fig. 16: Roentgenograms of decalcified cross sections from the lower third of Specimen 27. Note the posterior vessels supplying the lower end. Mercury and turpentine injection was used.

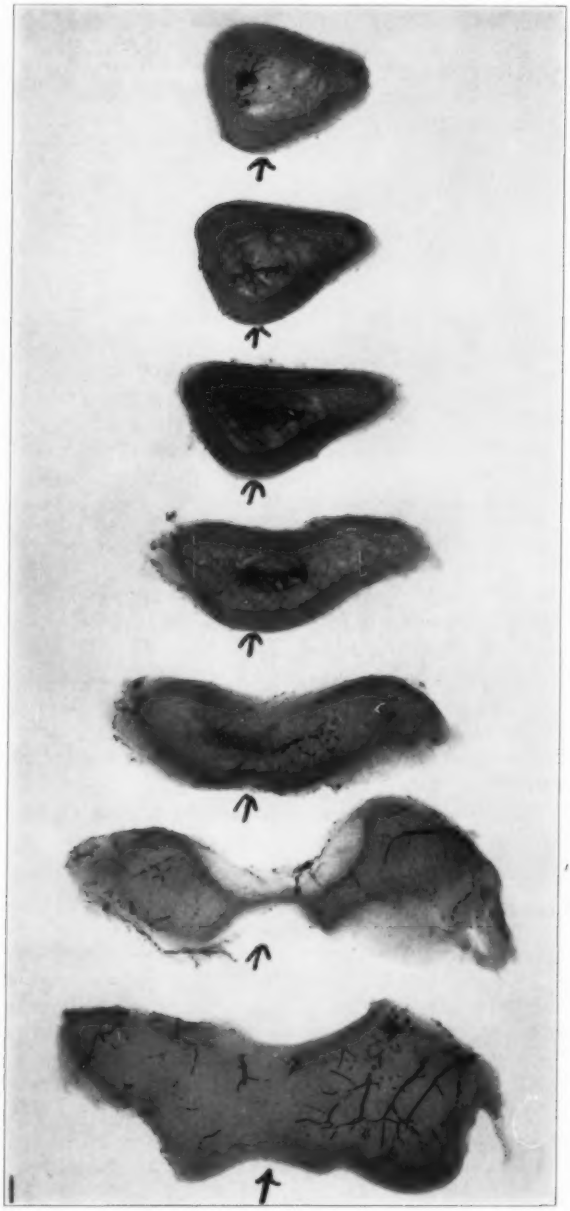

FIG. 16

Arteries of the Humeral Head

A constant anterolateral artery was found to enter the humeral head (Figs. 10 and 11). This artery was formed by the ascending branch of the anterior humeral circumflex entering the bone either at the upper end of the bicipital groove or by its branches entering the greater and lesser tuberosities (Figs. 13 and 14). On entering the bone the vessel

(which may be multiple) pursued a curved posteromedial course just below the obliterated epiphyseal line (Fig. 8) through the humeral head. The vessel seemed of sufficient importance to deserve a name and the term "arcuate artery" was therefore selected to describe it. The distribution of these vessels closely resembled that of the lateral epiphyseal arteries of the femoral head described by Trueta and Harrison. Small twigs were given off to the epiphysis and cartilage at right angles to the arcuate vessel. Contributions to the blood supply of the humeral head were also demonstrated to come from the posterior humeral circumflex artery as posteromedial arteries. Inconstant arteries were seen to enter the head posteriorly and anteriorly via the region of the attachment of the rotator cuff (Fig. 14).

Blood Supply of the Lower End of Humerus

The blood supply of the lower end had a fairly constant pattern. As has been previously stated, the descending branch of the main humeral nutrient artery reached the epicondylar regions on both sides. Arteries entered the medial and lateral epicondyles medially and laterally respectively, as well as posteriorly (Fig. 15).

Arterial twigs were demonstrated to be entering the trochlea and capitulum from all these sources and these vessels all appeared to anastomose freely. Vessels were also seen to enter the condyles from the region of the olecranon fossa. No significant nutrient contribution could, however, be demonstrated to enter the condyles or epicondyles anteriorly.

DISCUSSION AND CONCLUSION

It is worth repeating that in all of these bones the periosteum with its rich blood supply had been removed. A true picture of the blood supply can only be obtained by keeping this abundant source of arterial blood in mind. The constancy of the main nutrient artery of the humeral shaft is remarkable. It would appear to be prudent to guard against injuring this vessel in operations on the humeral shaft. The danger of damaging this artery will probably be greatest in open reductions of fractures of the mid-shaft of the bone. Fractures through the shaft at the junction of the middle and lower thirds will probably destroy the main nutrient artery at the time of injury. The upper end of the lower fragment will then depend for arterial blood supply on vessels entering from the periosteum and those ascending from the epicondyles. Extensive stripping of the periosteum of the lower fragment in open reductions in this region would probably be best avoided. The upper half of the shaft has an excellent blood supply from the ascending branch of the main nutrient artery and from the accessory nutrient arteries. This may account for the predilection of secondary malignant deposits for this part of the bone.

The main blood supply of the humeral head enters it anterolaterally above the common site of fractures of the surgical neck. Both bone ends thus have a good blood supply. This may account for the rapidity of union of these fractures. However, in operating on this region, whether for repair of rotator-cuff injuries or for open reduction of fracture-dislocations of the surgical neck, it is perhaps worth while bearing in mind that the main blood supply of the head enters it via the upper end of the bicipital groove or via the adjacent parts of the greater and lesser tuberosities. If damage to these vessels is avoided the viability of the humeral head may be preserved.

The importance of preserving muscular and ligamentous attachments when operating on the lower end of the humerus is well known. The size of the posterior arteries entering the epicondyles and condyles is, however, worth bearing in mind. If damage to these posterior vessels is avoided in operations on fractures in this region, the viability of the bone fragments may well be preserved and subsequent degenerative changes in the elbow joint may be avoided.

The intramedullary course of the nutrient arteries (Fig. 16) must mean that they

will be destroyed by the insertion of intramedullary nails. If at the same time an open reduction of the fractured shaft is performed, periosteal stripping of the bone ends will be inevitable. The blood supply of the shaft would then be unduly jeopardized. Both the branches of the main and accessory nutrient arteries in the medulla and the only possible local collateral circulation, the periosteal vessels, would be destroyed.

NOTE: I am indebted to Dr. Arnold Branch, Chief of Laboratory Services, and to Dr. V. D. Davidson, Chief of Surgical Service, Lancaster Hospital, New Brunswick, Canada, for their kind help and criticism; to Mr T. H. Dickinson and Mr. William Nickson for technical assistance; and to Miss Lois McNair, R.T., and Miss Margaret Fitzgerald, R.T., for the roentgenograms.

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Ischiofemoral Arthrodesis of the Hip

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For many years, arthrodesis of the hip has been an established method of treatment for tuberculosis and for primary or secondary degenerative and residual suppurative arthritis. In the early days of surgical treatment of the tuberculous hip, it was found that intra-articular excision of cartilage was insufficient. Haas, in 1922, and Hibbs, in 1923, each working independently, reported that the use of extra-articular grafting as a method of iliofemoral arthrodesis gave much better results than did the other method. At the New York Orthopaedic Hospital fusion was successfully obtained by the primary operation in 69 per cent of 163 patients treated by the Hibbs technique between 1923 and 1931[8]. Because of the hazards of prolonging the operation and because of the danger that the tuberculous infection might be disseminated, the interior of the joint was not operated upon in these procedures. When arthrodesis came to be applied to the painful osteo-arthritic hip, however, intra-articular excision of the cartilage was done more and more often, the purpose of this step being to remove the definite barrier which exists in this type of joint disease to the development of intra-articular fusion following union of the extra-articular graft to the femur and ischium. At the New York Orthopaedic Hospital, between 1935 and 1946, 117 patients were treated by hip-fusion operations for conditions other than tuberculosis; arthrodesis resulted from the initial procedure in 77 per cent of these patients[11]. Various types of iliofemoral arthrodesis were employed in these operations. The best results were obtained (1) by a combination of intra-articular fusion, Smith-Petersen nail fixation, and bone grafting and (2) by intra-articular arthrodesis and fixation with carpenter-type Vitallium nails inserted from three different directions in order that the hip might be stabilized in several planes of motion. Among ninety-three patients operated upon in this manner at the New York Orthopaedic Hospital from 1940 through 1952, fusion was obtained by the primary procedure in 87 per cent [10,11].

Trumble, in 1932, and Brittain, in 1941, described techniques of ischiofemoral arthrodesis designed to eliminate the harmful distraction force of adductor spasm upon an iliofemoral graft. In these procedures the graft is placed in an area that is usually free from tuberculous involvement. By the use of these techniques Trumble and Brittain hoped to achieve a higher percentage of successful fusion in the tuberculous hip. Both men inserted a tibial graft from the femur to the ischium. Brittain also performed intertrochanteric osteotomy with medial displacement of the distal fragment to a position beneath the graft.

The Trumble technique of ischiofemoral arthrodesis was popularized in this country by Van Gorder. He described the method, with modifications, in 1949, and reported that successful results were obtained in seven patients with tuberculous involvement. In 1953, Stratford reviewed thirty-six cases of tuberculosis in which a Trumble graft had been used. In approximately 70 per cent of these cases successful results had been obtained. Fracture of the graft had occurred in fourteen cases and failure of union of the graft at either the ischial or femoral end had occurred in nine.

Brittain described his technique in 1941 and reported that solid bony union had been obtained by the first operation in 80 per cent of thirty-five cases. In 1947, Langston reported that successful results had been obtained in 79 per cent of twenty-eight patients, twenty-five of whom had tuberculosis and three of whom had osteo-arthritis. He considered that the failures were due to technical faults. In 1948 Brittain reported that eighty-two successful fusions had been obtained in ninety-two patients by 105 operations.

The advantages of the Brittain method over the Trumble method result from the

FIG. 1-A FIG. 1-B

Figs. 1-A, 1-B, and 1-C: B. A., a nine-year-old colored female, with old suppurative arthritis. Iliofemoral fusion had been performed previously, the result being failure. One year after this initial surgery, a Trumble ischiofemoral arthrodesis was performed.

Fig. 1-A: Preoperative roentgenogram.

Fig. 1-B: Roentgenogram made three months after the operation, showing bone consolidation in the hip joint.

Fig. 1-C: Roentgenogram made eight and one-half months after the operation. Hypertrophy of the graft is evident.

Figs. 2-A, 2-B, and 2-C: R. W., a twelve-year-old white male upon whom a Hibbs hip fusion had been performed for tuberculosis. Fourteen months after the Hibbs procedure, a Trumble procedure was carried out because of persistent non-union at the hip joint. Bone union at the hip joint was apparent seven months after the addition of the ischiofermoral graft.

Fig. 2-A: Roentgenogram made before the Hibbs procedure was done.

osteotomy, for by this procedure temporary rest of the joint may be obtained and any existing deformity may be corrected. Furthermore, by medial displacement of the femoral shaft the stresses of weight-bearing are made to by-pass the diseased articulation to a greater extent. Medial displacement also decreases the possibility of graft fracture, for by this method the lever arm is shortened and fusion of the inferior surface of the graft to the distal fragment is obtained, the result of these two factors being a reduction in the amount of bending stress which falls on the graft.

There are several disadvantages to this method, however. Delayed union or even non-union of the osteotomy fragments may develop, and loss of position of the graft or of the femoral osteotomy fragments may also occur. The greatest objection is the fact that it is a blind procedure and that there is constant danger of hemorrhage or of injury to the sciatic nerve.

Some of these disadvantages can be eliminated by performing the operation through a posterior approach, as suggested by Mayer in 1948 and as reported by Foley in 1949 and by Cholmeley and Nangle in 1951. By this means the procedure is made safer, for the osteotomy can be done under direct vision and the graft placed accurately.

Eighteen ischiofemoral arthrodeses have been performed at the New York Orthopaedic Hospital since 1942. Thirteen of these operations were done for tuberculosis and

FIG. 1-C

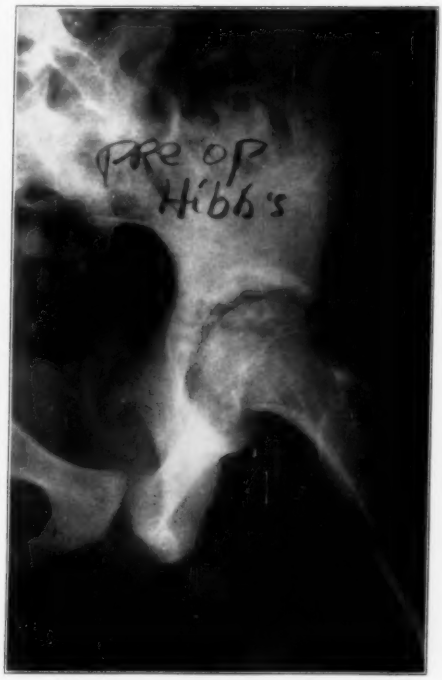

FIG. 2-A

FIG. 2-B

FIG. 2-C

Fig. 2-B: Roentgenogram made before the Trumble procedure was done.
Fig. 2-C: Hypertrophy of the graft is evident in this roentgenogram, made one year after the ischiofemoral arthrodesis.

FIG. 3-A

FIG. 3-B

Figs. 3-A, 3-B, and 3-C: J. V., a white male, fifty years old. Excision of a tuberculous greater trochanter had been performed five years before the Trumble procedure. The preoperative range of motion was well over 40 per cent of normal. The ischiofemoral graft fractured seven and one-half months after the operation, and, because of displacement of the fractured fragments, iliofemoral fusion was done.

Fig. 3-A: Preoperative roentgenogram.

Fig. 3-B: Roentgenogram made eleven months after the Trumble procedure, prior to iliofemoral procedure.

Fig. 3-C: Roentgenogram made eight months after the iliofemoral procedure, showing fusion across the joint.

FIG. 3-C

five were done for secondary osteo-arthritis; the latter condition resulted from trauma in one patient, from residual suppurative arthritis in two, from congenital deformity in one, and from radiation necrosis following x-ray therapy for carcinoma of the cervix in one.

An analysis of these cases has been made with respect to the relationship of eventual fusion, achieved by ischiofemoral grafting, and the following factors: (1) the degree of preoperative deformity of the hip, (2) the amount of destruction of the hip joint, and (3) the degree of motion present in the hip joint preoperatively.

PREOPERATIVE CONDITION

The age range of the patients at the time of operation was seven to fifty-three years. In all the patients with tuberculosis the disease was relatively quiescent and of long duration. In six of these patients an iliofemoral fusion had been performed, with subsequent development of pseudarthrosis (Table I). Abscesses had been drained in three patients at a time when there was marked active destruction of the joints. In two patients the greater trochanter had been excised because of tuberculous involvement. In all the five patients with non-tuberculous hips previous intra-articular fusion had been attempted, with result-

FIG. 4

FIG. 5

Fig. 4: R. R., a white female, eleven years old, upon whom a Brittain arthrodesis was performed for tuberculosis of the right hip. The fragments at the osteotomy site were solidly united twelve months after the operation. This roentgenogram, made forty-four months after the operation, shows extensive hypertrophy of the graft.

Fig. 5: R. B., a twelve-year-old white male, upon whom a Brittain arthrodesis was performed for tuberculosis of the hip. Extensive graft hypertrophy is apparent in the roentgenogram, made two years after the operation.

ant pseudarthroses. In one of these patients there was marked structural deformity and arthritic changes which had developed twenty-seven years after a closed reduction of a congenital dislocation of the hip. In five of the eighteen patients no previous hip surgery had been performed.

The amount of preoperative motion in the articulation apparently influenced the results, for in the patients who had more than 40 per cent of normal motion before the operation, solid fusion was obtained after an average of fourteen months, whereas in all other patients fusion was obtained after an average of only nine months.

THE TRUMBLE ARTHRODESIS

This operation was performed according to Van Gorder's modifications [14], a tibial graft three to four inches in length being used. The graft was placed obliquely from the femur to the ischium and was fixed at the femoral end by one screw. The angle that the graft made with the femur varied from 105 to 135 degrees.

Of the ten patients in this group, seven had tuberculosis and three had osteo-arthritis. The osteo-arthritis was due to trauma in the first patient, to previous suppurative arthritis with marked joint destruction in the second, and to radiation necrosis of the femoral head in the third. In all the patients with osteo-arthritis and in three of the tuberculous patients unsuccessful iliofemoral fusions had been done.

The time required before weight-bearing in a single spica could be allowed varied from two to seven months and the total time in plaster ranged from five to sixteen months. At the time of writing two of the patients were in the sixth month of postoperative care, and although fusion was progressing satisfactorily in these patients, it was too early for final evaluation. The operation upon one patient is listed as a failure because fracture of the graft with displacement occurred eleven months after the operation, necessitating

FIG. 6-A

FIG. 6-B

FIG. 6-C

Figs. 6-A, 6-B, and 6-C: S. C., a thirty-one-year-old white male upon whom a Brittain ischiofemoral arthrodesis was performed for tuberculosis of the hip. By thirteen months after the operation, the hip joint was solidly fused.

Fig. 6-A: Preoperative roentgenogram.

Fig. 6-B: Roentgenogram made three months after the operation.

Fig. 6-C: Roentgenogram made six years after the operation. Non-union at the osteotomy site, which allowed 15 degrees of painless motion, is apparent.

iliofemoral fusion (Figs. 3-A, 3-B, and 3-C). Eighteen months after the original surgery the joint was solidly fused.

Fractures of the graft occurred in four patients from five to eighteen months after the operation (Table II). All but one healed following immobilization in a single spica. All of these fractures occurred in tuberculous hips, in none of which had previous attempts at arthrodesis been done. Preoperatively there had been from 10 to 75 per cent of normal motion in these hips. None of the grafts were involved by the tuberculous process, and all the graft fractures appeared to be of the stress variety. In three patients with pseudarthroses of previous fusions, no fractures of the graft occurred and the development of the ischiofemoral fusion seemed more rapid than usual. Solid fusion was noted between three and one-half and seven months after the operation (Figs. 1-A through 2-C). Except in the case in which an iliofemoral fusion was performed twelve months after the Trumble procedure, fractures of the graft did not delay weight-bearing or, apparently, influence the occurrence of subsequent intra-articular fusion. It was impossible to determine from the roentgenograms when vascularization of the graft had been completed and, therefore, reliance was placed upon the appearance of the hip joint and upon the

TABLE I

	Total No. of Cases	Previous Treatment		Amount of Preoperative Motion	
		Attempted Fusion	Incision and Drainage	Less Than 40 Per cent (*Cases*)	40 Per cent or More (*Cases*)
Tuberculosis	13	6	3	10	3
Other	5	5	2	3	2
Total	18	11	5	13	5

TABLE II

	Total No. of Cases	Disease		Results				
		Tuberculosis (*Cases*)	Other (*Cases*)	Fusion of Joint (*Cases*)	Fracture of Graft (*Cases*)	Hypertrophy of Graft (*Cases*)	Failure (*Cases*)	No. of Further Operations
Trumble	10*	7	3	7*	4	3	1	1
Brittain	8	6	2	8	3	4	3	0
Total	18	13	5	15	7	7	4	1

* Note: in two cases it is too early to evaluate the results.

clinical evidence of solidity and subsidence of disease activity. Clinical evidence showed that the fusion was solid and trabeculations crossing the joint were demonstrated by roentgenograms from three and one-half to eighteen months after operation. The average time was eleven months.

Eight of the patients treated by the Trumble procedure have been followed for sixteen to forty months. In each, the joint is solidly fused and there is no evidence of disease. These patients have no more disability than that occasioned by a stiff hip. In three of these patients striking hypertrophy of the graft appears to be developing one or two years after operation (Figs. 1-A through 2-C).

THE BRITTAIN ARTHRODESIS

This operation was performed upon eight patients: for tuberculosis in six, for residual suppurative arthritis in one, and for osteo-arthritis in one. In the patient with osteo-arthritis closed reduction had been performed twenty-seven years previously for congenital dislocation of the hip and a severe structural deformity had subsequently developed. In the two patients with osteo-arthritis previous iliofemoral fusions had been done with unsuccessful results. No modification of Brittain's technique was made. The tibial grafts employed were from four to four and one-half inches in length. It was not necessary in any case to perform the osteotomy primarily in order to secure correction of a deformity.¶

It was considered important to displace the femoral fragment medially at least one and one-half inches. This was achieved in all but two patients. In one of the patients in whom this displacement was not obtained, healing occurred slowly and twelve months of immobilization was required. In the other necrosis of the graft and pseudarthrosis at the osteotomy site occurred.

Weight-bearing was allowed after three to ten months, and the total length of immobilization varied from four to seventeen months.

Intra-articular fusion of the joint occurred in all patients (Table II). Nevertheless the results in three patients were considered failures. In two of these patients necrosis and fracture of the graft and a pseudarthrosis at the osteotomy site developed (Figs. 6-A, 6-B, and 6-C). The hips of these patients became painless after two years, however, and 15 to 20 degrees of motion at the site of the previous osteotomy became possible. In the third patient the graft fractured but the hip joint fused after seventeen months of immobilization. The graft fragments united some time later, and a roentgenogram made seven years after the operation showed solid fusion and union of the fracture. None of the grafts became involved by the tuberculous process.

Four grafts showed marked hypertrophy from two to three years after operation. In these patients, the proximal fragment of the femur remained porotic for a long time, even though trabeculations were seen across the joint, indicating that intra-articular fusion had been obtained (Figs. 4 and 5).

In all patients the disease has remained quiescent for five to eleven years, and all, including the two with pseudarthroses at the osteotomy site, are leading essentially normal lives.

DISCUSSION

Successful arthrodesis of the hip joint can be achieved in a high percentage of cases by iliofemoral grafting, particularly when this procedure is combined with intra-articular fusion and internal fixation. Ischiofemoral arthrodesis is indicated if there is need to avoid diseased or avascular tissue and bone, for example, in patients with extensive tuberculous involvement of the acetabulum, ilium, or femoral neck, or in patients in whom fibrosis and sclerosis have developed following previous unsuccessful iliofemoral fusions.

The high incidence (39 per cent) of graft fracture encountered in this series of eighteen patients treated by ischiofemoral arthrodesis is disturbing; this complication constitutes the greatest threat to obtaining successful fusion by this method. Exclusive of involvement of the graft by the tuberculous process, which to the best of our knowledge did not occur in this series, two factors appear to be of significance in connection with this complication.

In the first place, the grafts are cortical in type. It is probably necessary to use this type of bone to provide strength, but revitalization of compact bone is known to be an extremely slow process. If the grafts are to remain strong until completely revitalized, they should be large and they should be protected from strain for a long period of time.

Secondly, ischiofemoral grafts, even after they have become united at both ends, are subjected to a high degree of stress in the presence of a mobile hip because they are placed in an eccentric position with relation to the center of motion of the joint. Intra-articular fixation will minimize this deleterious stress; for this reason, the subsequent development of fusion between the joint surfaces may well be a determining factor in the ultimate success of an extra-articular arthrodesis. If this factor is as important as it appears to be, then it would seem advisable, whenever feasible, to combine intra-articular with extra-articular fusion, or at least to confine the use of ischiofemoral grafts alone to those patients (1) in whom the articular-cartilage barrier has been destroyed by previous suppurative arthritis, (2) in whom the joint surfaces have been excised in a previous but unsuccessful iliofemoral-fusion procedure, or (3) in whom arthrodesis of the joint surfaces may be expected to occur spontaneously following extra-articular fusion because of the tuberculous nature of the disease process.

When ischiofemoral arthrodesis is indicated, the Trumble method with Van Gorder's modifications is favored. Since an osteotomy is an additional source of complications, it should be done only when necessary for the correction of the deformity and should be performed through an open approach.

It seems questionable whether the osteotomy, by eliminating motion and strain at the hip, can accelerate fusion of the joint or of the graft, for immobilization in a double spica is

maintained postoperatively for twelve weeks. Furthermore, it is quite probable that the osteotomy fragments unite before the grafts become consolidated and long before the joint surfaces fuse, unless perhaps an intra-articular arthrodesis has been performed concomitantly.

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DISCUSSION

Chondrosarcoma

(Continued from page 1038)

occurs more often in the younger age group than does the chondrosarcoma. Most of our cases have occurred in the metaphysis of a long bone. We have, however, seen two in the pelvic girdle. In our thirteen examples of this condition, the original roentgenogram indicated a benign process. The danger of mistaken diagnosis lies in the biopsy. Fields in many of these tumors contain bizarre nuclei, binuclear cells. However, with experience, one learns to recognize the varied mixture of chondroid myxoid and the fibromatoid components that label the tumor as benign. There is a condensation of cells at the periphery of the tumor which is quite characteristic. Benign chondroblastomata rarely contain enough cartilage to simulate grossly a chondrosarcoma at the time of surgery.

We call the final tumor chondroblastic osteogenic sarcoma; the term may need revision. In this tumor, although it may be predominantly a cartilaginous tumor in certain areas, the proliferating malignant cells produce a distinct lace-like osteoid matrix. When such fields are found in a bone tumor, it will behave more like an osteogenic sarcoma than a chondrosarcoma, and it is more logical, in our opinion, to include it with osteogenic sarcoma. It occurs more commonly around the knee than anywhere else. It is found in the young age group and has a very strong tendency to metastasize.

The Alveolar Soft-Part Sarcoma

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In 1945 Ravich and associates reported a case of malignant granular-cell myoblastoma involving the urinary bladder. In 1946, Ackerman and Phelps reported a case of a similar tumor originating in the gluteal region. Smetana and Scott in 1951 and Christopherson and associates in 1952 each reported a group of cases in which this same type of tumor was present.

The neoplasm reported by these men has been variously described as an alveolar soft-part sarcoma, a non-chromaffin paraganglioma, and a malignant granular-cell myoblastoma. It has frequently been confused with renal-cell carcinoma, liposarcoma, and undifferentiated sarcoma, and it has also been diagnosed as a benign neoplasm. The author believes that it is relatively unknown to orthopaedic surgeons and that a wider knowledge of its characteristics will lead to its more frequent recognition. In the 1954 *Instructional Course Lectures of The American Academy of Orthopaedic Surgeons*, only very brief mention was made of this tumor in the chapter on "Primary Soft-Tissue Tumors of the Extremities". The author of this chapter reported no cases, merely stating that more study is needed to verify that this tumor is a distinct entity [2].

Recently a case of such a tumor was encountered on the orthopaedic service of the Barnes Hospital in St. Louis, Missouri. Sections from this tumor and from a similar tumor found in the surgical pathology files at Barnes Hospital were reviewed by Dr. L. V. Ackerman, who confirmed the diagnosis of alveolar soft-part sarcoma [1].

CASE 1. B. L. B., a twenty-year-old colored female, was admitted to the General Surgical Service at Barnes Hospital on July 11, 1954. For one year the patient had been aware of a tumor mass in the posterior aspect of the left thigh. There was no history of trauma, and the only symptom other than the presence of the mass was a dull aching pain which was noted when the patient was sitting. There was no history of cough or chest pain, and the past history and family history were negative. Examination on admission revealed a mildly obese, colored female who was not in acute distress. Temperature was 37 degrees centigrade; pulse, 104 pulsations per minute; blood pressure, 140 systolic and 70 diastolic; and respiration, 20 per minute. The only positive finding of the remainder of the examination was a firm mass at the apex of the left popliteal space. This mass measured six by four inches and was neither tender nor hot. The tumor was adherent to the deep structures but not to the skin, and there were no vascular or nerve changes distal to the mass. No enlarged inguinal nodes were observed, and the findings of a routine urine and blood examination were within normal limits. The blood count was normal. The clinical appearance of the tumor on admission was that of either a liposarcoma or a fibrosarcoma of the thigh.

On July 14 an incisional biopsy of the tumor was performed, and on the basis of the pathological findings a diagnosis of alveolar soft-part sarcoma was made.

By July 20, 1954, it was realized that pulmonary metastases were present. At this time the orthopaedic service was consulted concerning the advisibility of amputation. Due to the discomfort caused by the tumor mass it was decided that a high thigh amputation should be carried out, local resection being considered inadvisable because of the size and position of the tumor. The amputation was done on July 26, 1954. A mild infection developed in the operative wound, which was drained and closed secondarily. The patient was discharged with a healed stump. A one-year follow-up reveals that she is alive and is using a prosthesis; the pulmonary metastases, which are still present, are enlarging slowly.

CASE 2 (contributed by Dr. W. F. Keller, Oklahoma City, Oklahoma). H. M., an eleven-year-old white female, was in excellent health until a non-painful mass was discovered in the region of the scapula. At operation a tumor mass, five by four centimeters, was locally excised. This tumor was attached to the periosteum of the scapula. The postoperative course of the patient was uneventful, and now, three years later, she is reported to be in good health. An x-ray examination, made in November 1955, showed no evidence of pulmonary involvement.

PATHOLOGY

A careful study of the gross specimen from Case 1 revealed a large firm soft-tissue tumor occupying the posterior aspect of the distal third of the thigh. Grossly there was no involvement of the femur, sciatic nerve, or popliteal vessels. The tumor mass had for the most part completely replaced the semitendinosus and had markedly displaced the biceps femoris and the semimembranosus. Gross invasion of the adjacent adductor muscles was also present. Both the sciatic nerve and the popliteal vessels were compressed but did not appear to be invaded by the tumor. The cut surface of the tumor was yellowish-gray with focal areas of necrosis and hemorrhage. The consistency of the tumor was rubbery, and there appeared to be a pseudocapsule from which fibrous strands extended into the depths of the tumor mass, producing a lobulated effect. There was no attachment to the skin, and the fascia lata was free of invasion. The tumor appeared to arise from and to grossly invade the skeletal muscles.

The tumor was 180 millimeters long and sixty-four millimeters wide at its greatest diameter. The portions of the femur, popliteal vessels, and sciatic nerves which were adjacent to it were sectioned at various intervals, and histological sections were made. In none of these sections was there any evidence of invasion of the adjacent structures, even though grossly the tumor was only one to two millimeters from the sciatic nerve, three millimeters from the femoral vessels, and twelve millimeters from the femur (Fig. 1-A).

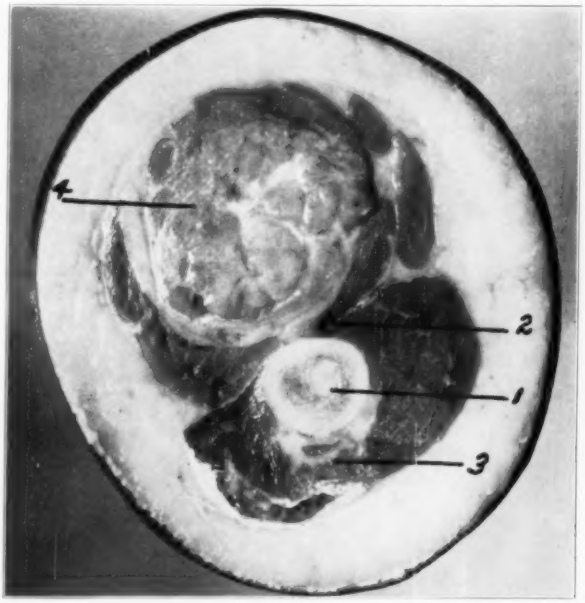

FIG. 1-A

Case 1. Photograph showing a cross section of the thigh made through the middle of the tumor.

Sections of the neoplasm itself revealed that the tumor had a very uniform appearance and that it was composed of groups of cells which were characteristically pseudo-alveolar or organoid in arrangement (Fig. 1-B). The cytoplasmic outline of each cell was distinct, and the cells were moderate in size and oval or polyhedral in shape. The cytoplasm was only faintly eosinophilic and was finely granular. Fat stains revealed only a very slight mount of cytoplasmic fat. The nuclei of these cells were usually eccentrically placed and were fairly basophilic. Many of the nuclei were vesicular and contained one or two nucleoli. Only a few mitotic figures were present.

The cells were arranged in groups of from fifteen to sixty or more. Each group was surrounded by a boundary of reticulin fibers which was clearly visible in specimens stained for reticulin. It was these groups of cells which accounted for the alveolar-like configuration of the tumor. There was a striking absence of reticulin fibers between the individual cells. Within the central portions of the cellular groups necrosis and even absence of cells was seen. These factors increased the alveolar appearance of the tumor, as seen in the sections. Between the groups of cells were numerous small vascular channels, and in several

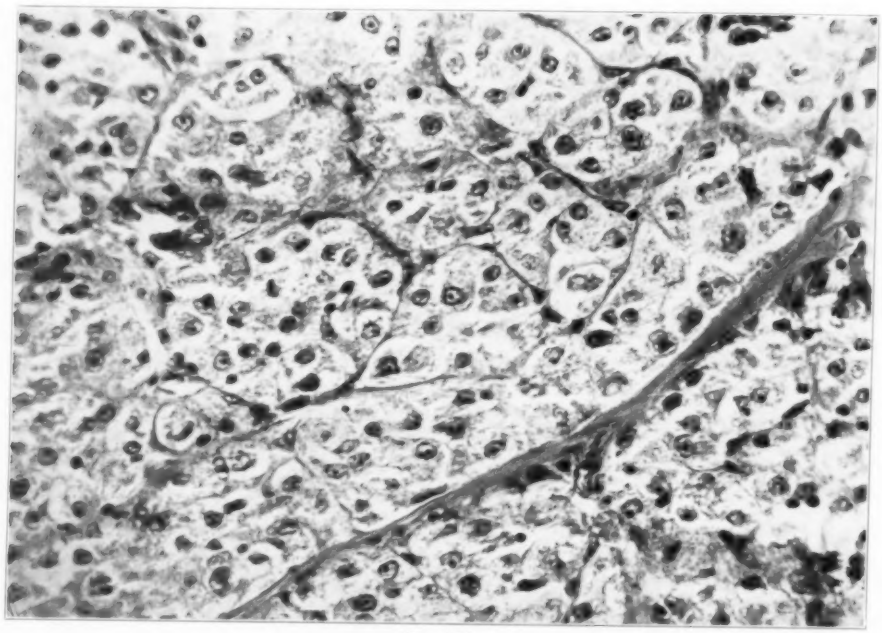

FIG. 1-B

Case 1. Photomicrograph (× 400) showing characteristic pseudo-alveolar pattern of the cells. The cells have distinct boundaries and contain vesicular nuclei. Mitotic figures are very rare.

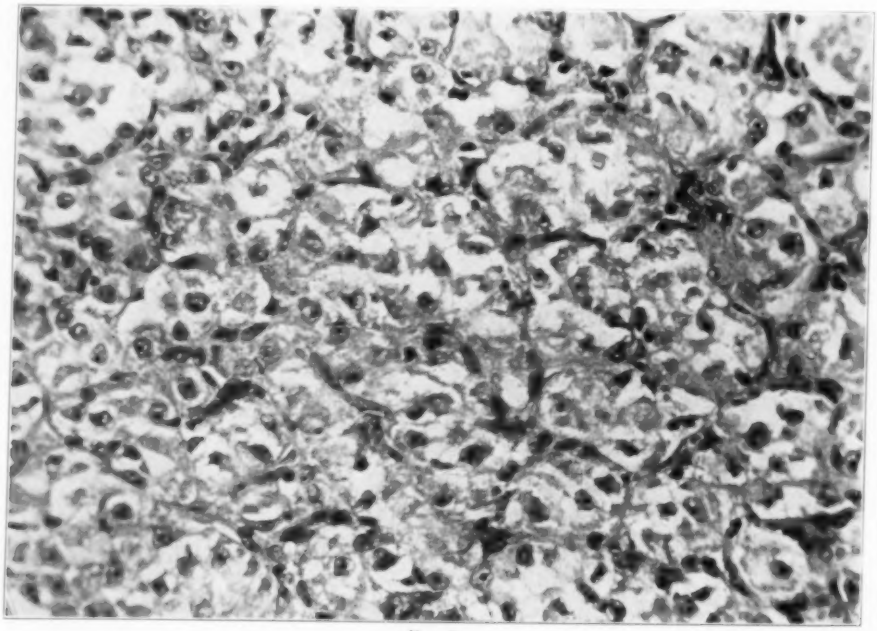

FIG. 2

Case 2. Photomicrograph (× 400) showing the same pseudo-alveolar pattern as that which appears in the section shown in Fig. 1-B.

TABLE I

Series	Cases Followed	Local Recurrence	Deaths	Known Metastases	Location of Metastases				
					Lung	Brain	Bone	Liver	Nodes
Smetana	10	3	5	9	8	3	3	2	2
Christopherson	12	3	4	6	6	2	1	1	1
Stein*	2	0	0	1	1	0	0	0	0
Randall	1	0	0	1	1	0	0	0	0
Ackerman	1	1	1	1	1	0	1	0	1
Total	26	7	10	18	17	5	5	3	4

*The patient followed for twelve months is known to have pulmonary metastases.

sections tumor thrombi could be seen in sinusoids. The pale cytoplasm and dark nuclei of the cells of this tumor somewhat resemble those of a renal-cell carcinoma. In the past this resemblance has led to a search of the kidneys for a primary tumor. The absence of acinar formation and the very small amount of cytoplasmic fat in this tumor should rule out a diagnosis of renal-cell carcinoma. A diagnosis of liposarcoma has been considered at times, but there is almost always an absence of sudanophilic cytoplasm in this tumor, which, of course, rules out this diagnosis.

The histological appearance of the tumor from Case 2 was in all ways similar to that of the tumor just described (Fig. 2).

DISCUSSION

Smetana and Christopherson together have reported a total of twenty-six cases, in twenty-two of which the patients were followed for from one to eighteen years. Nineteen of the twenty-six patients were women and seven were men, and they were all between three and thirty-eight years of age. All of the tumors appeared clinically to be slow growing masses which were seldom painful. The majority of the tumors were located in the thigh, but a number of others were found in the retroperitoneal tissue; the buttock, neck, shoulder, and arm were also sites of occurrence.

In twenty-six of the cases reported in the literature there was adequate follow-up, and statistics concerning these cases are presented in Table I. At the time of writing eighteen of the patients were known to have metastatic lesions and ten had already died as a result of the tumors. The shortest period of follow-up in this group was twelve months, and the patient was known to have pulmonary metastases but was still alive. The longest period of follow-up was eighteen years (Christopherson), and the patient was also known to have pulmonary metastases. The lungs were the most common site of metastisis, but the brain, bones, liver, and lymph nodes were also rather common sites.

The chief form of treatment used was local resection of the tumor. In one case in which the tibia was involved, amputation was done (Christopherson). X-ray therapy was employed in some instances but proved to be of very little value (Smetana, Ackerman, Randall). Of the twenty-six patients listed in Table I, twenty-two were treated by local excision of the tumor and seven showed clear evidence of local recurrence.

Patients with an alveolar soft-part sarcoma may have a long protracted course even when metastatic lesions are present. This is well demonstrated by Ackerman's patient, who survived almost four years following the original diagnosis, and by Randall's patient. In one of Christopherson's cases, eighteen years passed before metastatic lesions became apparent.

The origin of this tumor is not known. Its organoid appearance is similar to that of paraganglion tissue and of the carotid and aortic bodies. It has been suggested that this tumor originates from paraganglion tissue in the region of the adductor canal (Johnson).

The presence of paraganglion tissue in the region of the abdominal aorta in dogs has been described by Hollingshead in an extensive review of chromaffin tissue and paraganglia.

It would appear from a study of the cases reported that local resection of this neoplasm should be undertaken only when the tumor is small and when a very wide resection can be carried out. Although the tumor is slow growing, its metastasizing ability has been well demonstrated and it should probably be treated by more radical surgery than local resection.

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Congenital Heart Disease and Scoliosis

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It has been a clinical impression that scoliosis is more prevalent among patients with congenital heart disease than in the general population. This study was done in order to determine the validity of this impression and also in the hope of shedding some light on the factors which influence the development of spinal curvatures in patients with congenital heart disease.

The material used for this study was roentgenograms of patients with known congenital heart disease; the cases were taken from the cardiovascular files of Stanford University Hospitals. Four hundred and twenty-five roentgenograms were reviewed. The scoliosis was measured according to the method described by Cobb and others, as seen in Figure 1. This series included 212 males and 213 females.

There were three cases of congenital bony abnormality—one of a spina bifida occulta, one of fork ribs, and one of kyphoscoliosis and multiple spinal abnormalities as well as several anomalous ribs. These cases of congenital bony deformity were excluded from this series because bone abnormalities may themselves initiate a spinal curvature.

As a control, 200 roentgenograms reported negative for pulmonary or cardiac disease were reviewed. These roentgenograms were of individuals fourteen to thirty-five years of age, for it seemed likely that if a curvature were going to develop, it would be present by the time the patient was fourteen years old. The control roentgenograms were otherwise taken at random from the files of the x-ray department at Stanford University Hospitals. No congenital abnormalities of the spine or thorax were noted in the control group.

After reviewing a number of roentgenograms, it was concluded that no lateral deviation of less than 10 degrees would be considered since the position of the patient, differences in limb length, pelvic tilt, and inaccuracies in the measurements often produced minimal functional curvatures.

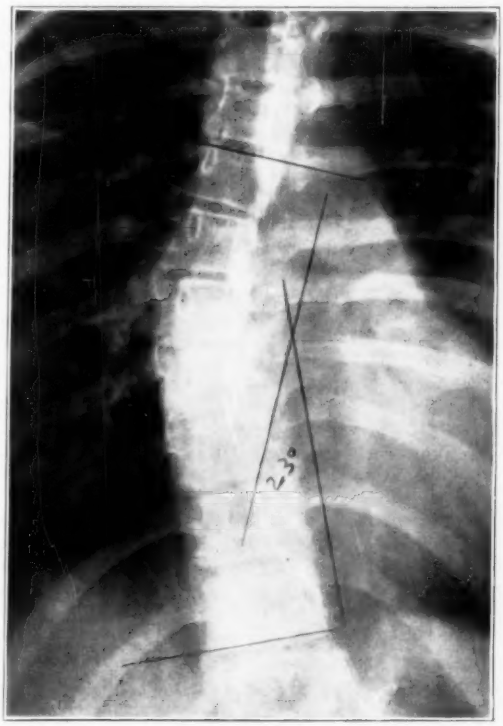

FIG. 1

RESULTS

The cases were studied with attention to the following factors: (1) incidence of scoliosis in patients with heart disease; (2) incidence of scoliosis

TABLE I

PATIENTS IN CONGENITAL HEART DISEASE GROUP WITH SCOLIOSIS

Case	Age	Sex	Congenital Heart Disease	Cardiac Size	Type of Scoliosis	No. of Degrees	Apex	Span	Surgery
B.B.	14	F	Tetralogy of Fallot	Enlarged	Left thoracic	27	T-8	T4-T12	Yes
A.G.	31	F	Tetralogy of Fallot	Enlarged	Left thoracic	21	T-6	T4-T8	Yes
J.L.	6	M	Tetralogy of Fallot	Enlarged	Right thoracolumbar	10	T-8	T2-L3	Yes
A.W.	5	M	Tetralogy of Fallot	Enlarged	Right thoracic	15	T-10	T4-L4	No
C.T.	5½	F	Tetralogy of Fallot	Enlarged	Right thoracic	65	T-7	T4-T10	
					Left thoracolumbar	83	L-2	T10-L4	Yes
G.M.	14	F	Tetralogy of Fallot	Enlarged	Right thoracolumbar	10	T-8	T5-T10	
					Left thoracolumbar	21	L-1	T11-L4	Yes (also had right aortic arch)
L.H.	7	F	Truncus arteriosus	Enlarged	Left thoracic	20	T-6	T3-T8	Yes (2)
J.V.	9	M	Truncus arteriosus	Enlarged	Right thoracic	4	T-9	T6-T11	
					Left thoracolumbar	12	L-2	T11-L3	Yes
R.S.	7	M	Interventricular septal defect	Enlarged	Left thoracolumbar	10	T-10	T5-L3	
E.H.	26	F	Patent ductus	Normal	Right thoracic	6	T-10	T4-T11	Yes (2)
					Left thoracolumbar	14	L-2	T11-L3	
W.W.	29	M	Patent ductus	Enlarged	Right thoracic	16	T-6	T2-T12	Yes
P.J.	29	M	Patent ductus	Normal	Right thoracic	14	T-9	T5-T12	Yes
H.P.	28	F	Patent ductus	Enlarged	Right thoracic	17	T-8	T5-T11	Yes
M.R.	16	F	Patent ductus	Normal	Right thoracolumbar	10	T-10	T5-L3	Yes
L.P.	9	F	Patent ductus	Enlarged	Right thoracic	26	T-9	T5-T12	Yes
					Left thoracolumbar		L-3	T12-L4	No (lumbar curve not measurable)
J.A.	14½	F	Patent ductus	Enlarged	Right thoracic	56	T-4	T5-T11	Yes (coarctation)
J.S.	29	F	Interauricular septal defect	Enlarged	Right thoracolumbar	55	T-6	T4-L4	No
S.I.	27	F	Interauricular septal defect	Enlarged	Left thoracolumbar	17	T-6	T2-L2	No
B.A.	6	F	Interauricular septal defect	Enlarged	Right thoracolumbar (aberrant pulmonary venous return; curvature showed at 4 years of age.)	12	T-12	T4-L3	No
Q.D.	32	M	Coarctation of the aorta	Enlarged	Left cervicothoracic	12	T-7	T5-T9	Yes
P.M.	21	F	Right-sided aortic arch	Enlarged	Right thoracolumbar	13	T-10	T7-L2	No (also tetralogy of Fallot)
C.P.	15	F	Idiopathic cardiac hypertrophy	Enlarged	Left thoracolumbar	32	T-12	T4-L3	No
R.H.	4	M	Unknown	Normal	Right thoracic	32	T-8	T5-T12	
					Left thoracolumbar	27	L-2	T12-L4	No

in the control group; (3) change in curvature following surgery; (4) relation of cardiac enlargement to scoliosis; (5) type of curvature; (6) degree of curvature; (7) type of heart disease; and (8) apex of deviation.

In the 422 cases of congenital heart disease studied, it was found that there was an incidence of 5.5 per cent (twenty-three cases) of scoliosis of 10 degrees or over (Table I). However, if only the seventy-two individuals fourteen years old and over were consid-

TABLE II

PATIENTS IN CONTROL GROUP WITH SCOLIOSIS

Case	Age	Sex	Type of Scoliosis	No. of Degrees	Apex	Span
S.M.	32	F	Right thoracolumbar	15	T-9	T7-L1
L.P.	34	F	Right thoracolumbar	10	T-10	T7-L1
G.S.	25	M	Left thoracic	19	T-4	T2-T6
A.W.	25	F	Left thoracic	18	T-5	T2-T7
T.J.	33	F	Right thoracolumbar	13	L-2	T11-L4
J.G.	32	F	Right thoracolumbar	12	T-7	T3-L2
R.B.	34	F	Right thoracic	10	T-6	T4-T9
J.T.	20	F	Right thoracic	12	T-7	T4-T9
			Left thoracolumbar	18	T-12	T9-L3
C.P.	26	M	Right thoracic	7	T-5	T4-T7
			Left thoracic	10	T-9	T8-T11
			Right lumbar	14	L-1	T12-L2
M.W.	31	F	Right thoracic	15	T-7	T4-T9
O.M.	32	F	Right thoracolumbar	12	T-10	T9-L1
H.H.	26	M	Right thoracic	13	T-10	T8-T12

ered, then the incidence of spinal deviation of 10 degrees or greater was 19 per cent (fourteen cases).

In the control group twelve out of 200 (6 per cent) had a spinal curvature of 10 degrees or greater (Table II).

In none of the cases reviewed was there an increase in or development of a spinal curvature following cardiac surgery. It should be mentioned, however, that the interval of observation following this surgery was often short.

Among patients without cardiac enlargement 3.6 per cent were found to have scoliosis, whereas 5.8 per cent of patients with an enlarged heart had scoliosis. Many of those with enlarged hearts were very young children in whom the effect of cardiac enlargement during spinal growth would not yet be apparent—if this effect is a factor in the development of scoliosis.

In the older patients with heart disease, that is among the seventy-two patients fourteen years of age and over, of whom 19 per cent had scoliosis, fifty-three had cardiac enlargement. All the patients in this group who had scoliosis (except two) had cardiac enlargement.

Table III demonstrates that seventeen of twenty-three patients with congenital

TABLE III

Configuration of Curve	Control Group	Congenital Heart Group
Right thoracic	3	5
Left thoracic	1	3
Right thoracolumbar	5	5
Left thoracolumbar		3
Right thoracic, left thoracolumbar	1	6
Left cervicothoracic		1
Left thoracic, right thoracolumbar	1	
Right thoracic, left thoracic, right lumbar	1	
	12	23

Ten out of twelve patients in the control group have a right curve. Seventeen out of twenty-three patients in the congenital-heart-disease group have a right curve.

TABLE IV

	No. of Patients	No. of Patients with Scoliosis of 10 Degrees or More	
Congenital Heart Disease with Cyanosis			
Stenosis of pulmonary artery	10	0	
Tetralogy of Fallot	117	6	
Eisenmenger's syndrome	3	0	
Single ventricle	1	0	
Dextroposition of aorta	7	0	
Pulmonary atresis	1	0	
Truncus arteriosus	7	2	
	146	8	5.5 per cent
Congenital Heart Disease with Potential Cyanosis			
Interventricular septal defect	64	1	
Patent ductus arteriosus	107	7	
Interauricular septal defect	51	3	
Epstein	1	0	
	223	11	4.9 per cent
Congenital Heart Disease without Cyanosis			
Mitral stenosis	2	0	
Coarctation	39	1	
Persistent right aortic arch	4	1	
Subaortic stenosis	1	0	
Situs inversus viscerum	3	0	
Aortic stenosis	1	0	
Idiopathic hypertrophy of heart	1	1	
	51	3	5.9 per cent
Unknown	5	1	20.0 per cent

heart disease had a curvature to the right. One might speculate on the possibility that cardiac enlargement or a disturbance in cardiovascular dynamics predisposes a curvature to the right. The control group showed a similar predilection, however, and it is well known that a right thoracic curvature predominates in individuals with idiopathic scoliosis.

Table IV shows that there was little appreciable difference percentagewise in the number of curvatures in the cyanotic patients, the potentially cyanotic patients and those without cyanosis.

The apex of the deviation and the span of the curvatures are given in Table I. Little information could be obtained regarding the presence or type of lumbar curvatures, for the lumbar spine was not visualized in the chest roentgenograms which comprised the material for this survey.

DISCUSSION

Irvine-Jones reported that 4 per cent of 100 patients with congenital heart disease had spinal abnormalities. However, no distinction was made between developmental curvatures and congenital abnormality. Taussig reported similar findings and was impressed by the high incidence of congenital abnormalities of the spine in individuals with congenital heart disease. Streeter suggested that spinal abnormality in the embryo may cause stresses which produce congenital cardiovascular anomalies. However, it must be pointed out that many curvatures do not develop until the individual is around ten to fourteen years of age. It certainly would seem from our study that in a good percentage of cases scoliosis develops and increases in severity with spinal growth. This is borne out

particularly by the difference in incidence among the younger and older patients, and it suggests that some factor during bone development and growth causes spinal curvature.

Attempting to find some explanation for the higher percentage of scoliosis in patients with congenital heart disease, we considered the possibility that increased heart size or abnormal thrust of the heart or great vessels might exert some etiological influence. We attempted to obtain information by utilizing ballistocardiograms, but these gave negative results. The factor of cardiac enlargement was difficult to evaluate because of the necessity of depending upon the radiologist's reports. Furthermore, we had no way of knowing the duration of the cardiac enlargement in many cases.

It might be considered that there is some disturbance in the circulation of the growing vertebral bodies, particularly in cyanotic patients. This, however, even if true, does not account for the fact that most curvatures show a deviation to the right. Also the roentgenograms demonstrate no evidence of bone atrophy. Another point is that the wedging of vertebral bodies which one sees at the apex of the curvature in severe cases is a secondary change resulting from compression on the concave side of the curve. Furthermore, it seems that the incidence of scoliosis among cyanotic patients is no higher than that among acyanotic patients with congenital heart disease (Table IV).

Donzelot and associates reported that the incidence of spinal deviation in a series of 623 cases of congenital heart disease was 27.5 per cent. They considered any curvature of 5 degrees or greater a deviation. They stated further that other deformities of the bony thorax frequently occur, such as kyphosis and precordial bulging, that these deformities prove that the bony thorax must mold itself upon its contents, and that in congenital heart disease the contents seem to be of high importance. Other lesions of the thorax in growing children, such as intrathoracic tumors, empyemas, and extensive thoracoplasties also cause scoliosis. One might speculate that the spinal curvature in some of the cases studied were related to abnormalities of the intrathoracic contents caused by congenital heart disease.

It is likely that most of the curvatures of the control group were of the idiopathic variety. This type of curvature was probably also present in a similar percentage of the patients in the congenital-heart-disease group. A point which should be considered, although it cannot be substantiated, is that idiopathic scoliosis occurs more commonly in patients with congenital heart disease than in the general population.

It must be considered that there was a tendency to include in this sample of congenital-heart-disease cases a large share of seriously ill patients. Similarly it must also be considered that those who come into the hospital for chest roentgenograms may well be suffering from almost any other disease. The fact that a random sample of roentgenograms showing congenital heart disease exhibits definitely more scoliosis than does a random sample of routine chest roentgenograms of people of similar ages is evidence that either scoliosis is associated with congenital heart disease or that a patient with both diseases is much more likely to come to a hospital for treatment than is a patient with heart disease alone. The random chance of obtaining these results by use of the chi-square test is significant at the 0.5 per cent level indicating that the findings are statistically significant and demonstrating that scoliosis is more prevalent in patients with congenital heart disease than it is in the general population.

SUMMARY

The incidence of scoliosis was 19 per cent in those over fourteen years of age as compared with an incidence of 6 per cent in a control group of 200 patients of a like age. There was a predominance of right thoracic curvatures, but there was no definite pattern which could be attributed to any one kind of heart disease.

NOTE: Grateful acknowledgement is made to Dr. Ann Purdy and Dr. Lincoln E. Moses for their assistance.

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LETTER TO THE EDITOR

Tumor of the Wrist of Anomalous Muscle Origin

To the Editor:

In the December 1955 issue of the Journal, Dr. Robert E. Van Demark presented a case of anomaly of the palmaris longus which appeared to be a tumor of the volar aspect of the wrist. In commenting upon this case, the author drew attention to the scarcity of references to such muscular anomalies in the medical literature, especially the English literature, and pointed out that this anomaly must be considered in the differential diagnosis, along with the common types of synovitis and tumors of the soft tissues of the wrist.

In order to supplement the list of references presented by Dr. Van Demark and in order to further describe the condition which is caused by the palmaris longus anomaly, I would like to mention two additional papers. In the October 1948 issue of the British Journal of Surgery, Dr. Roy Goulding reported a case of the same anomaly in a paper entitled "Gross Hypertrophy of the Palmaris Longus Muscle Simulating a Tumor of the Forearm". In this paper he presented some very interesting considerations and introduced five references describing the anatomy of the lesion. Shortly thereafter, but before reading Dr. Goulding's paper, I reported two cases of this anomaly in a paper written with Dr. P. Gamberoni. This paper was published in the December 16, 1949 issue of La Prensa Medica Argentina and was entitled "Falsa Tenosinovitis de la Muñeca: Anomalía del Músculo Palmar Menor y Celulitis Crónica Subpalmar" (False Tenosynovitis of the Wrist: Anomaly of the Palmaris Longus Muscle and Subpalmar Chronic Cellulitis). In both of the cases reported the condition had originally appeared to be chronic tenosynovitis of the wrist, but the operation had revealed hypertrophic chronic cellulitis of the fatty cellulous tissue between the muscle belly of the anomalous palmaris longus and the flexor digitorum sublimis. Pathological study of the excised tissue had borne out this diagnosis, and there was no further complaint following removal of the fatty cellulous tissue.

I believe this complementary data on the condition described by Dr. Van Demark is of interest, especially since one of the cases described represents the only time that a pathological study of excised tissue has been made.

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Two Unusual Dislocations at the Wrist

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This is a report of two cases of unusual dislocations at the wrist—one, an acute anterior dislocation of the ulna, the other a posterior subluxation of the lunate.

Acute Anterior Dislocation of the Distal Extremity of the Ulna

This condition could be properly described as a posterior dislocation of the radius and carpus in relation to the ulna at the wrist inasmuch as the ulna is fixed in the trochlea fossa of the elbow and does not change its relationship there. The term used in this report is more descriptive and describes the lesion more graphically.

Very few cases of this dislocation have been reported. In 1912, Cotton and Brickley described a case of acute anterior dislocation of the ulna at the wrist, and in the same year, Hitzrot, in a discussion before the New York Surgical Society, referred to a similar case. Both were fresh cases, and the dislocations were easily reduced. Cox, in 1942, reported a case which had been overlooked for more than three weeks. His case required open reduction. His experience makes it obviously important that a case of acute anterior dislocation should not be overlooked.

The condition presents a very characteristic and striking deformity. When the extremity is examined, the wrist appears peculiarly narrow, and the hand appears as if it were perched on an apex of the forearm, instead of on the normal broad oval of the wrist. The distal end of the ulna is absent from its position on the side of the wrist. It is this disappearance of the bony prominence of the ulna that accounts for the narrowed appearance of the wrist. When viewed from the side there is no undue prominence of the distal end of the ulna because the head is deep in the flexor tendons and is buried in the soft tissues. On palpation, however, a thickening can be felt in the front of the wrist where the head of the ulna is located.

Roentgenograms of the wrist are curiously deceptive and are easily read to be negative. The distal end of the ulna is moved anteriorly and somewhat radially so that in the anteroposterior position there is more overlap of the radius and ulna than in the normal wrist. This can easily be misinterpreted as being an oblique roentgenogram of the wrist joint; however, if an anteroposterior view of each wrist is made at the same time, then one can see the extent to which the ulna overlaps the radius (Fig. 1-A). In the lateral view the distal end of the ulna is anterior to the radius so that the dorsal cortex of the ulna lies in front of the volar cortex of the radius (Fig. 1-B).

The mechanism of this injury is not clear but is apparently due to hypersupination. Since the ulna is fixed in the trochlea fossa at the elbow and cannot rotate at all, when the wrist and forearm go into full supination, further forceful supination is apparently followed by a backward displacement of the radius and carpus with forward dislocation of the ulna.

A twenty-five-year-old stevedore was lifting heavy crates containing cans of oil. He had piled the crates to a height of about ten feet when the pile started to tilt. A crate struck his outstretched hand when it was in a relatively fixed position. The patient could not describe the exact mechanism of the injury, but severe pain immediately developed and he could not move his wrist.

When examined one hour after the accident, the patient had severe pain. His left wrist and forearm presented the peculiar clinical deformity previously described. The hand had the appearance of being perched on top of a point. The wrist itself was not swollen or thickened but had become narrowed. The forearm tapered towards this narrow point. All motion of the wrist was restricted because of severe pain. Roentgenograms of the wrist revealed the displacement of the ulna without fracture. Roentgenograms of the opposite wrist were made for comparison and when both films were laid side by side, it was clearly evident that the distal end of the ulna was dislocated volarly and radially. In the anteroposterior projection of the disloca-

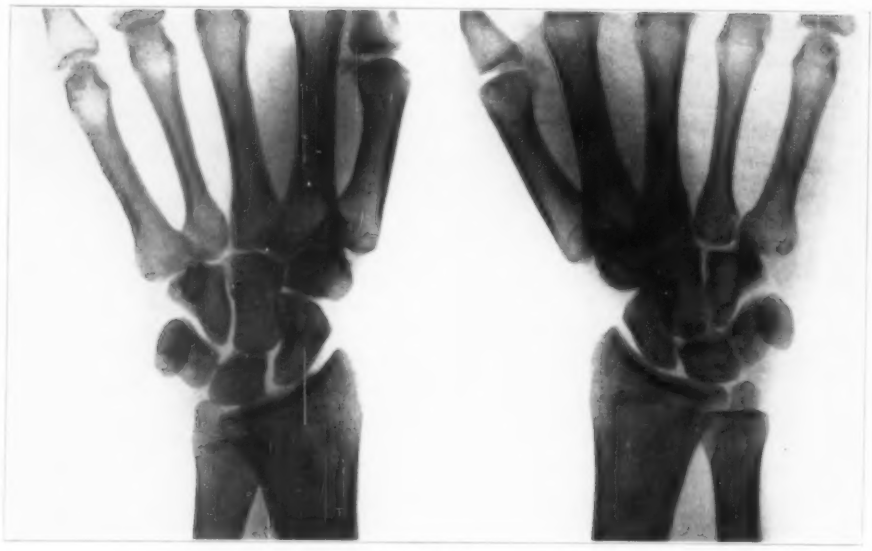

FIG. 1-A

tion the radius overlapped the ulna much more than on the normal wrist. In the lateral projection the distal end of the ulna was displaced forward so that the posterior cortex of the ulna was adjacent to the anterior cortex of the radius.

The patient was given a general anaesthesia. Some firm traction was applied to the wrist, and it was rotated gently. As the manipulation was being performed, a definite snap was felt, and there was an immediate reappearance of the normal contour of the forearm. The distal end of the ulna could now be felt and seen on the ulnar side of the wrist. The reduction remained stable, and motion of the wrist did not recreate the dislocation. A short plaster cast was applied from the metacarpal heads to the elbow and the cast was left on for a period of three weeks. Upon its removal the patient rapidly regained a completely normal wrist with no restriction of motion or loss of strength (Fig. 1-C).

FIG. 1-B

FIG. 1-C

Posterior Dislocation of the Lunate Without Fracture

Dislocation of the lunate is an uncommon condition. When it occurs, the displacement is usually volar so that the lunate is displaced on the anterior aspect of the wrist. The occurrence of posterior dislocation of the lunate is very rare. Speed, in his book on fractures and dislocations, describes a case very similar to the one to be presented. In most of the literature on fractures, the discussions and descriptions of dislocations of the lunate are concerned with the anterior dislocation, and only rarely is there mention of posterior dislocation.

In contrast with anterior dislocation of the ulna, the clinical deformity resulting from posterior dislocation of the lunate is not striking. The wrist appears somewhat larger than normal, and there is a mild swelling on the dorsum of the wrist. This swelling is not great and looks like a small ganglion. However, when the swelling is palpated, it is found to be very firm but can still be mistaken for an enlarged prominence of a carpal bone.

Roentgenograms, however, show marked and significant changes in the organization of the carpal bones. In the anteroposterior projections, one can see that the capitate has moved proximally and has spread the navicular and triquetrum apart (Fig. 2-A). This roentgenographic appearance in the anteroposterior view is characteristic of any dislocation of the lunate. The same disorganization is seen when the lunate dislocates volarly or when the entire carpus dislocates posteriorly around the lunate as in perilunar dislocation. The lateral and oblique views are somewhat more difficult to read, but better indicate the true pathological picture (Fig. 2-A). It is apparent that the lunate is not displaced in the volar aspect of the wrist and there is an abnormal prominent bone on the dorsum of the

FIG. 2-A

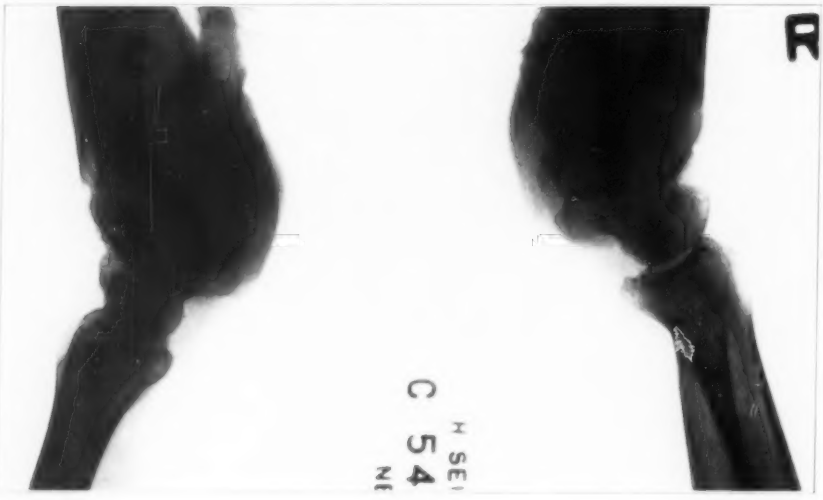

FIG. 2 B

wrist. This is somewhat more clearly demonstrated by the oblique view which shows the lunate to be situated dorsally.

The mechanism of this injury is apparently the reverse of forward dislocation of the lunate. In the cases in which the lunate is displaced anteriorly the wrist is forcibly hyperextended, and the lunate is squeezed from the joint. In posterior dislocation, the wrist is hyperflexed, and the lunate is pushed out dorsally.

A fifty-two-year-old milkman had, approximately three months prior to the examination, fallen off a truck. The patient fell about four feet, and as he fell, his right hand was caught in the door handle of the truck resulting in a marked hyperflexion of the wrist. Immediate pain and swelling of the wrist developed and he consulted a physician. Roentgenograms were made which were reported to be negative for fracture. The patient was given some physiotherapy. When he failed to improve after a few weeks, he was referred for new

FIG. 2-C

FIG. 2-D

roentgenograms; again, these were reported negative for fracture. He continued to complain of pain in the wrist, marked weakness of grip, and restriction of motion.

When examined, the wrist showed a mild diffuse swelling on the dorsum. This was due to a mass of bony hardness on the dorsum of the radial aspect of the wrist joint which was quite sensitive to touch. The strength of grip was markedly reduced. There was no atrophy of the forearm or arm. There was marked restriction of motion of the wrist, only 25 degrees of volar flexion and 5 degrees of dorsiflexion being possible.

Roentgenograms of the wrist were made and it was immediately evident in the anterior view that the lunate was displaced. In the lateral view, it was seen that this displacement was in the dorsal direction.

The patient was admitted to the hospital, where an excision of the dislocated lunate was performed. At operation, it was found that the lunate was approximately three-fourths out of the wrist joint. A simple dorsal incision exposed the lunate which was easily freed and removed. No attempt was made to replace the lunate into the wrist joint since it was feared that this might induce aseptic necrosis and permanent stiffness of the wrist.

The postoperative course was uneventful and the patient's pain and sensitivity disappeared. Within a period of two months he had regained 80 degrees of dorsiflexion of the wrist and 80 degrees of volar flexion. His strength of grip improved, and the patient returned to his former occupation on the milk truck. When seen one year later, he stated that his wrist gave him no severe pain, but gave him slight pain with changes of weather. He had excellent strength in his wrist. Dorsiflexion and volar flexion were the same as they had been two months after operation.

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Spondyloschisis Following Spine Fusion

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The cause of spondyloschisis and spondylolisthesis has been the subject of controversy since the condition was first described by Robert in 1855. A complete history of this controversy and a summary of the evidence supporting the congenital and traumatic theories were well presented by Rowe and Roche in 1953. It is not the purpose of this paper to discuss the arguments for or against either theory, but to present a case in which spondylolisthesis occurred spontaneously in an apparently intact fourth lumbar vertebra following fusion of the lumbosacral spine.

In 1950, a case of "spondylolisthesis aquisita" was reported by Unander-Scharin of Sweden. In this case the spondyloschisis occurred in the third lumbar vertebra which had appeared normal in previous examinations. The spondylolisthesis was observed five years after fusion of the third, fourth, and fifth lumbar vertebrae and the sacrum, the fusion having been done for low-back pain associated with degeneration of the fourth lumbar intervertebral disc. Unander-Scharin presented a thorough survey of the literature. He had been unable to find any reports of previous cases of true "acquired spondylolisthesis" occurring in the absence of severe trauma. It is interesting to note that in the author's case also the spondylolisthesis developed following fusion of the spine at a lower level.

CASE REPORT

Mrs. L. C., thirty-six years of age, wife of a practicing physician and mother of six children, was examined on September 25, 1948, because of pain about the right side of the lower lumbar spine. The patient gave a history of several previous episodes of backache, these episodes having occurred over a period of fifteen years, usually following bending or heavy lifting.

Examination in 1948 revealed a tired-looking, well developed, large-boned woman, five feet ten inches tall and weighing about 170 pounds. Examination of the spine revealed flattening of the lumbar spine, a list to the left, and spasm of the lumbar muscles. The symptoms subsided after a few days' rest, only to recur with resumption of normal activity.

Roentgenograms made in April 1949 (Figs. 1 and 2) revealed no significant anomalies. The intervertebral disc spaces were of average height. A few hypertrophic spurs were noted.

Bracing and exercises were instituted. Despite this treatment there was recurrent back pain with later radiation of the pain into the left sciatic region and depression of the left Achilles' reflex.

Further roentgenograms of the lumbar spine showed that no change had occurred since the previous examination (Figs. 3 and 4). No spondyliolisthetic defect was noted at any level.

Pantopaque myelography, September 22, 1949, revealed an extradural defect on the left side of the spine at the lumbosacral level.

On September 26, 1949, a completely herniated disc was removed from the lumbosacral interspace by means of a limited laminotomy performed on the left side of the spine. The interspace between the fourth and fifth lumbar vertebrae was also explored on the left side, without removal of bone. No disc herniation was found at that level.

A fusion of the fifth lumbar vertebra to the sacrum was carried out by means of Hibbs' technique, additional bone being supplied from the posterior crest of the right ilium.

The postoperative course was uneventful, and relief of pain was complete. A lumbar body jacket was worn for several weeks and a spinal brace for six months. Six months after surgery, roentgenograms revealed that the fusion was solid (Figs. 5, 6, 7, and 8). Immobilization of the spine was discontinued. The patient remained asymptomatic and carried out all of her household activities without complaint for two years.

In March 1952, thirty months after fusion, the patient noted a mild mid-lumbar ache with fatigue and with radiation of pain into the right hip and leg. A few days later she bent forward to lift her youngest child from the floor and experienced severe pain in the lumbosacral area and right buttock. Later this pain was aggravated when she coughed, sneezed, twisted, turned, or bent. There was no radiation of pain into the thigh or calf and no paraesthesia.

Examination revealed a flat lumbar spine with muscle spasm, restriction of motion, and a slight list to the right. Pain was not relieved by bed rest or adhesive taping.

FIG. 1
Anteroposterior x-ray, April 1949.

FIG. 2
Lateral x-ray, April 1949.

FIG. 3
Right oblique x-ray, September 1949.

FIG. 4
Left oblique x-ray, September 1949.

FIG. 5
Postoperative lateral x-ray, February 1950.

FIG. 6
Postoperative left oblique x-ray, February 1950.

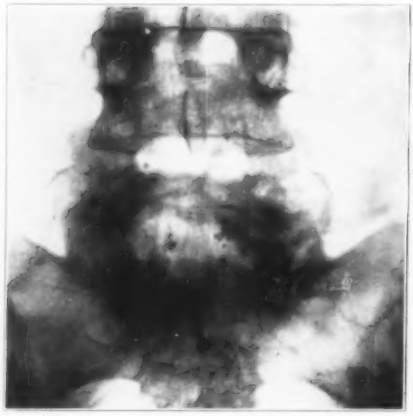

FIG. 7
Postoperative anteroposterior x-ray, Feb. 1950.

FIG. 8
Postoperative right oblique x-ray, Feb. 1950.

FIG. 9
Anteroposterior x-ray, May 1952.

FIG. 10
Lateral x-ray, May 1952.

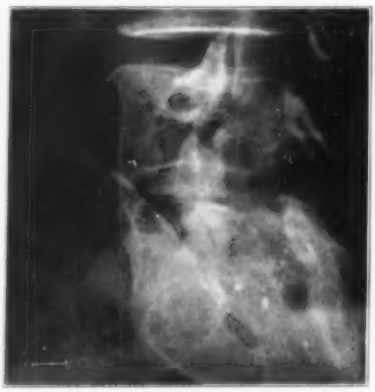

FIG. 11
Right oblique x-ray, May 1952.

FIG. 12
Left oblique x-ray, June 1952.

FIG. 13
Lateral x-ray, January 1953.

FIG. 14
Left oblique x-ray, January 1953.

FIG. 15
Right oblique x-ray, January 1953.

FIG. 16
Lateral x-ray, October 1954.

FIG. 17
Right oblique x-ray, October 1954.

FIG. 18
Left oblique x-ray, October 1954.

Roentgenograms of the lumbosacral spine made April 11, 1952, revealed that the lumbosacral joint was solidly fused but that there was a transverse defect through the right side of the isthmus of the fourth lumbar vertebra. In the previous roentgenograms, which were carefully reviewed at that time, the isthmic area of the fourth lumbar vertebra was well shown, but no defect was evident (Figs. 1 through 8).

Symptoms subsided rapidly with bed rest and use of a low-back brace. Pain recurred after a few weeks, however, extending to the left side. In May 1952, the lumbar spine was flat, and there was tenderness in the lumbosacral region, muscle spasm, and restriction of motion. Roentgenograms made May 4, 1952, revealed bilateral defects in the isthmic portion of the fourth lumbar vertebra. These defects were irregular and showed no eburnation (Figs. 9, 10, and 11).

Immobilization was carried out with a plaster-of-Paris body jacket. Subsequent roentgenograms made in 1952 and 1953 and in October 1954 (Figs. 12 through 18) revealed persistance of the isthmic defects. The symptoms have gradually subsided, however, and the patient has discarded the low-back support, does all of her own housework, and has only occasional lumbar discomfort with fatigue.

DISCUSSION

A case of bilateral spondyloschisis occurring in a previously normal vertebra in an adult is reported. The cause of this defect is not known, but it is suggested that it is the unusual stress which results from fusion of the spine at a lower level. One previous case of spondyloschisis occurring in this manner has been reported. These two cases indicate that defects through the isthmic portion of a previously normal lumbar vertebra may occur in an adult without severe trauma. It seems improbable that any direct operative trauma to the involved neural arch or its blood supply could have caused this phenomenon in the author's case, for the isthmic area was not disturbed in the operation and no bone was removed from the neural arch. The defects in our case occurred bilaterally and only the left side of the fourth and fifth lumbar intervertebral discs was explored.

CONCLUSION

No final conclusion can be drawn as to the cause of these defects. It is suggested, however, that they may represent stress or fatigue fractures which were caused by alterations in the stresses following stiffening of the adjacent vertebral joints.

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Hemipelvectomy: Surgical Technique

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The hemipelvectomy, or hindquarter amputation, removes the entire lower limb, including most, and sometimes all, of one innominate bone. Billroth performed the first hemipelvectomy as early as 1889, but we are indebted to Gordon-Taylor for establishing the operation as a safe procedure and for reporting the results in the largest series of successful cases that have been recorded. He has emphasized the importance of liberal blood transfusions to combat shock by replacing the blood loss during the operation.

Pringle described the surgical technique in 1916 and the procedure is now well standardized. Numerous accurate reports in the literature cover all phases of the operation, but a satisfactory series of step-by-step illustrations of the anatomy and technique of hemipelvectomy has not been published. It is the belief of the authors that such a pictorial exposition would be helpful, especially to those who by choice or necessity perform a hemipelvectomy occasionally.

INDICATIONS

The indications for a hemipelvectomy are fortunately very few in number. Certain patients with malignant tumors of the soft tissues and bones, chronic osteomyelitis of the pelvis or proximal portion of the femur, massive cartilaginous tumors of the innominate bone, and dissecting aneurysm of the femoral artery have been subjected to hindquarter amputation. Large cartilaginous tumors which are benign or of low-grade malignant growth are considered by some authors to be the principal indication for this operation. The decision to operate should be made only after a surgical or needle biopsy, and consideration of the pathologist's report. There is some question as to whether the procedure should ever be undertaken for palliation.

PREOPERATIVE PREPARATION

The patient's serum protein, hemoglobin, and blood count should be at an optimum level. A thorough cleansing enema is given the night before surgery. A douche is administered to women. A Foley catheter may be inserted into the bladder just prior to the operation. Catheterization of the ureter on the involved side is optional. In some cases, this may be helpful in identifying the ureter during dissection within the pelvis. A minimum of four pints of whole blood should be available in the operating room so that transfusions may be administered continually during the operation.

Anaesthesia

The anaesthetic agent should be chosen by the medical anaesthetist and it will vary with the characteristics of each case. The authors prefer general anaesthesia, although spinal anaesthesia, alone or in conjunction with general anaesthesia, may be satisfactory.

Preparation in the Operating Room

The patient is positioned on his unaffected side. Transfusions of intravenous fluids, including blood, are started in the sound limb and the arms. A purse-string suture is placed about the anus. If the patient is a man, the inner aspect of the opposite thigh is properly prepared, and the scrotum and penis are sutured to it. The operative field is

then prepared. Drapes are arranged in a manner to give extensive access to the inguinal and gluteal regions as well as to the front and back of the abdomen. The patient is then placed on his back.

OPERATIVE TECHNIQUE

The Anterior Dissection

The procedure is carried out in three parts, consisting of the ilio-inguinal, the ilio-gluteal, and the posterior portions. The ilio-inguinal or anterior exposure is made first. It begins as far back on the crest of the ilium as is accessible with the patient in the supine position (Fig. 1,*A*). The cut extends forward to the anterior superior iliac spine and then curves gently downward and medially paralleling the inguinal ligament to the pubic tubercle (Fig. 1,*B*).

The dissection is deepened through the subcutaneous fat and fascia to the iliac crest, going between the attachments of the abdominal muscles superiorly, and the tensor fasciae latae and the glutaeus medius distally. The skin flaps are retracted. The external oblique, the internal oblique, and the transverse abdominal muscles are detached from the ilium. Branches of the deep circumflex iliac artery can be ligated if necessary.

The dissection now enters the cavity of the pelvis (Fig. 1,*C*). The extraperitoneal fat is separated by blunt dissection from the fascia over the iliac muscle. The interior of the pelvis is palpated for the presence of enlarged lymph nodes, and in some cases it may be desirable to open the peritoneum to examine the abdominal glands and the liver for metastases. The peritoneum is closed and if, at this time, there are no contra-indications to continue with the operation, a warm laparotomy pad is placed in the wound.

In the next part of the operation the length of the inguinal ligament is incised longitudinally at its attachment to the fascia lata (Fig. 1,*B*). Branches of the external pudendal, the superficial epigastric, and the superficial circumflex iliac arteries are ligated as they are encountered. The inguinal ligament is detached at the anterior superior iliac spine and at the pubic tubercle separating the anterior abdominal wall from the bony pelvis. The inguinal ligament is then retracted upward. The spermatic cord is drawn aside proximally, together with the inguinal ligament and the anterior abdominal wall (Fig. 2,*A*).

Blunt dissection is continued through the loose areolar tissue and fat into the pelvis. The deep circumflex iliac artery traverses the outer portion of the wound, and ordinarily need not be ligated (Fig. 2,*B*). The lumbo-inguinal nerve is severed in the pelvis (Fig. 2,*A*). The inferior epigastric artery is exposed and ligated in the middle third of the wound. This artery should be preserved if the external iliac artery is ligated distal to it. Some authors are of the opinion that the inferior epigastric artery is essential to the blood supply of the anterior abdominal wall and should always be preserved if possible.

The dissection is continued deeper into the pelvis between the loose areolar tissue and the extraperitoneal fat, so as to expose the external iliac artery and vein and the femoral nerve (Fig. 2,*B*). The external iliac artery is isolated between clamps, severed, and triple ligated. This does not, however, ensure against subsequent troublesome bleeding because of the rich collateral circulation which is present in the gluteal region. The internal iliac artery is not ligated although some of its branches are tied in the gluteal region later in the operation.

After the external iliac artery has been ligated, the blood is expressed from the limb by means of an Esmarch bandage, care being taken not to dislodge emboli of the tumor when present. Next, the external iliac vein is clamped, severed, and doubly ligated. The femoral nerve lies close to the lateral aspect of the external iliac artery and it can be severed now, or at a later phase of the operation.

The pubic bone is exposed subperiosteally as far as the symphysis by detaching the rectus abdominis muscle superiorly and the adductor muscles inferiorly (Fig. 2,*C*). The bladder is retracted upward out of the way. The pubic bone then is transected with an

osteotome about one-half inch lateral to the symphysis. There is usually no troublesome bleeding from the retropubic venous plexus, especially in men. In cases where the tumor either lies in close proximity to the pubic bone or actually involves it, it is necessary to make the osteotomy at the symphysis, or as far from the tumor as possible. Care must be exercised not to injure the bladder or the urethra.

The large wound is packed lightly with warm laparotomy pads after bleeding has

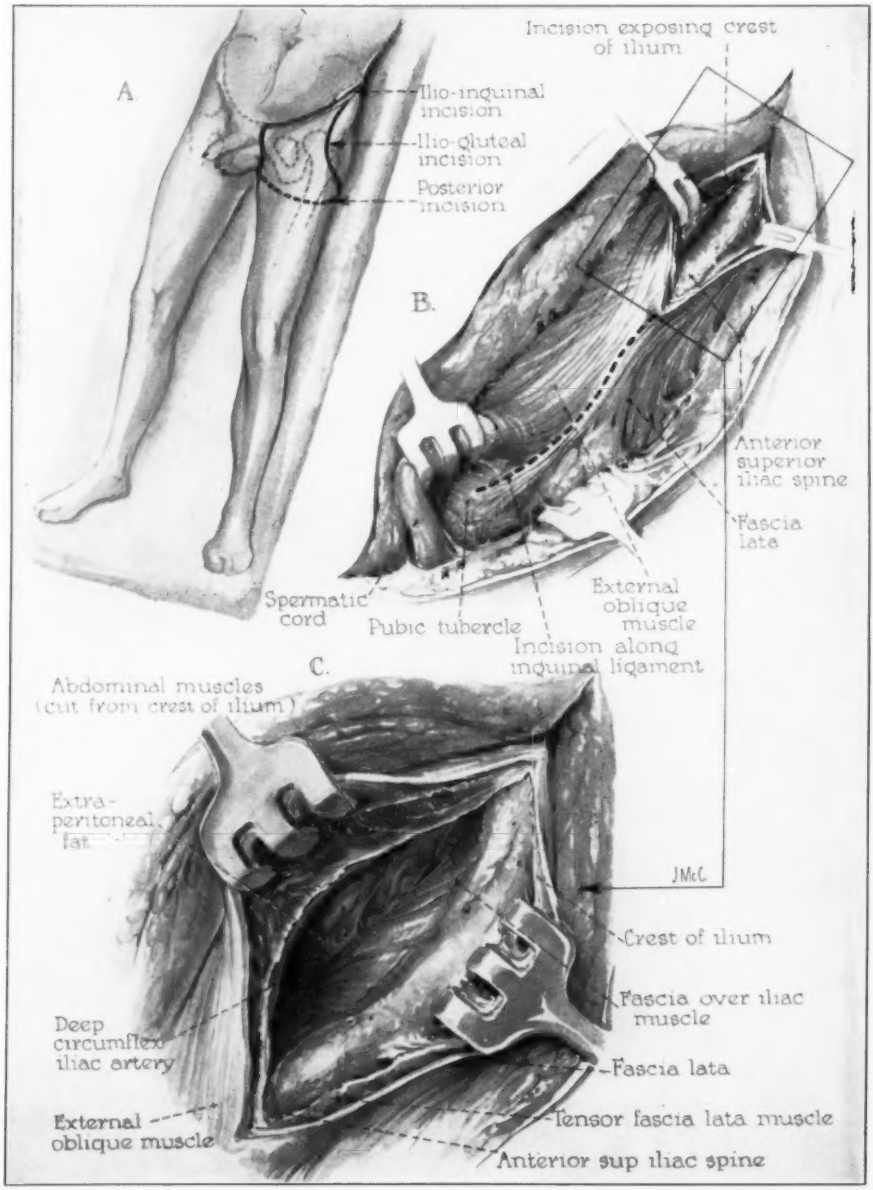

FIG. 1

been controlled. The patient is then turned on his sound side and the drapes are adjusted and reinforced preliminary to the second phase of the amputation.

Gluteal Dissection

The anterior incision is first extended backward along the iliac crest to the region of the posterior superior iliac spine. The iliogluteal exposure then begins from the site

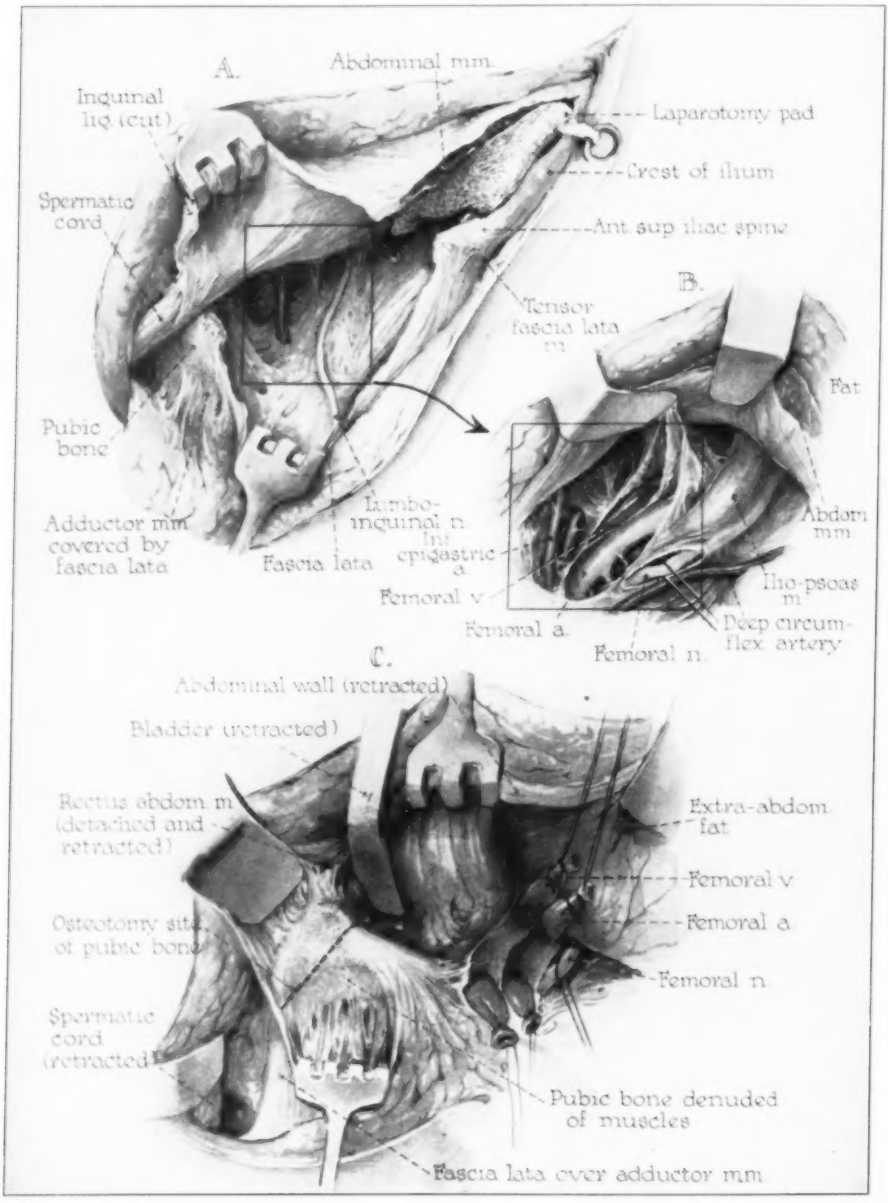

FIG. 2

of the start of this extension and extends straight down the thigh to approximately two inches below the greater trochanter where it assumes a considerable convexity, forming a skin flap. Subsequently, it will be prolonged backward around the posterior aspect of the upper portion of the thigh (Fig. 3,A).

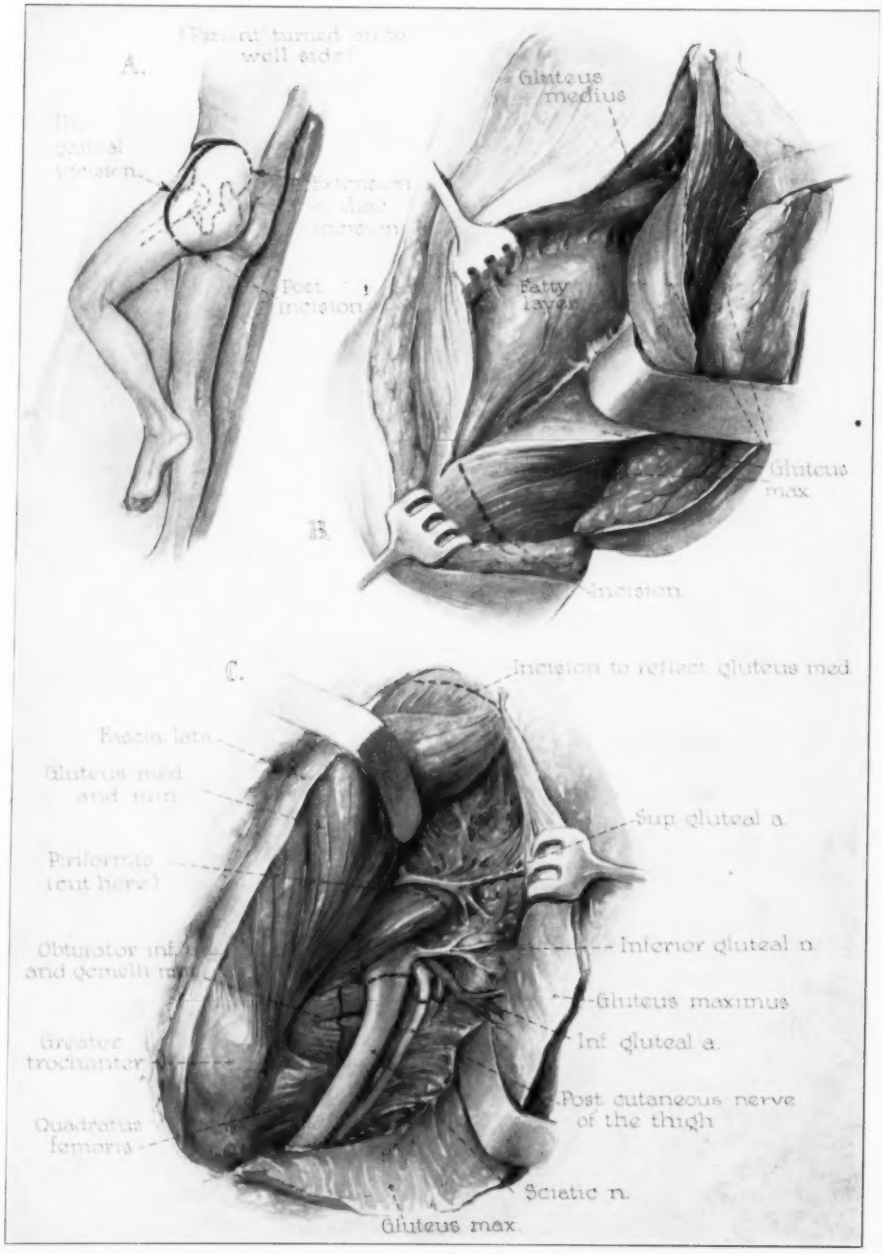

FIG. 3

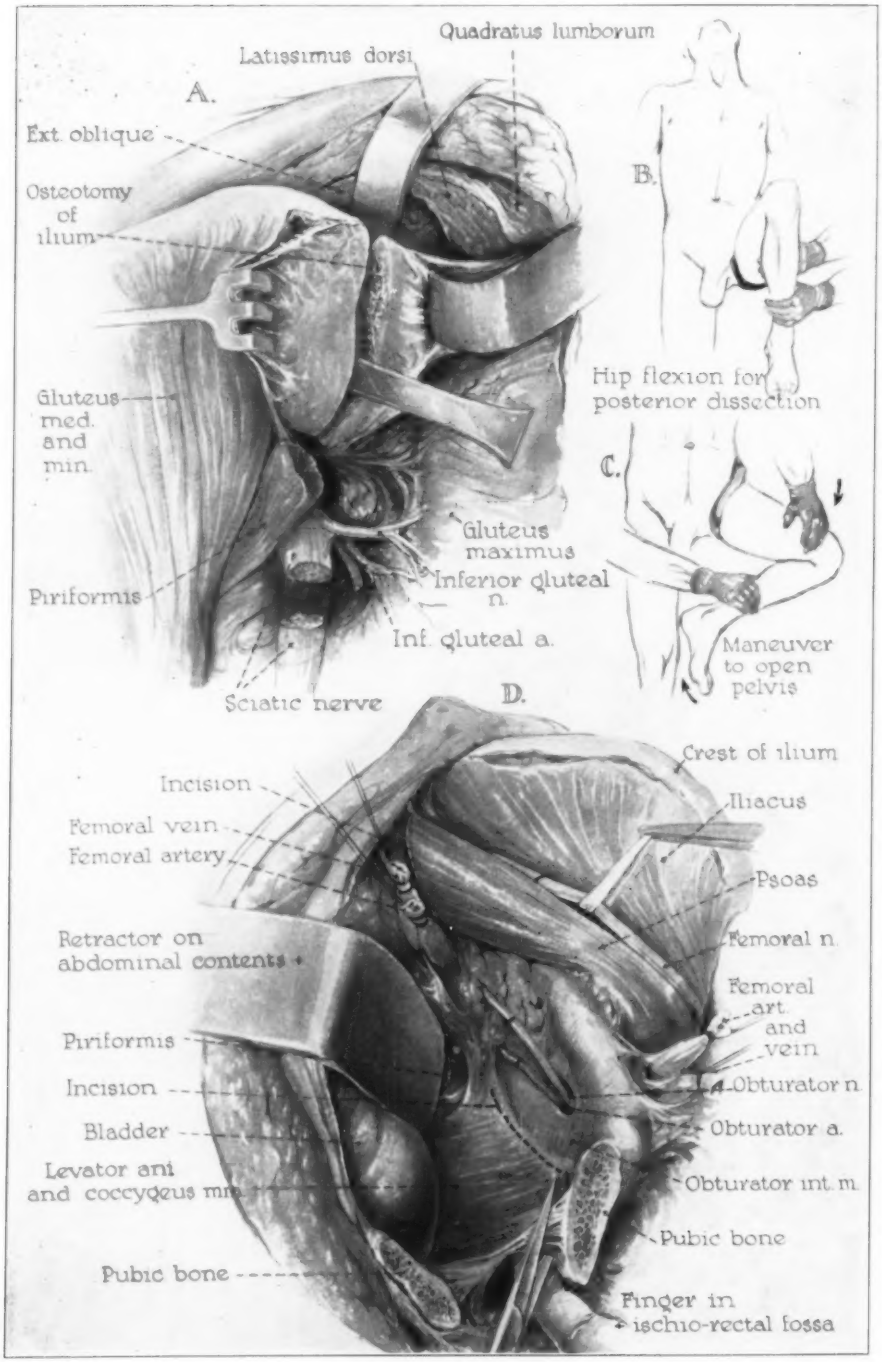
Quadratus lumborum
Latissimus dorsi
A.
Ext. oblique
Osteotomy of ilium
Gluteus med. and min.
Piriformis
Gluteus maximus
Inferior gluteal n.
Inf. gluteal a.
Sciatic nerve
B.
Hip flexion for posterior dissection
C.
Maneuver to open pelvis
D.
Crest of ilium
Incision
Iliacus
Femoral vein
Femoral artery
Psoas
Retractor on abdominal contents
Femoral n.
Femoral art. and vein
Piriformis
Incision
Obturator n.
Bladder
Obturator a.
Levator ani and coccygeus m.
Obturator int. m.
Pubic bone
Pubic bone
Finger in ischio-rectal fossa

FIG. 4

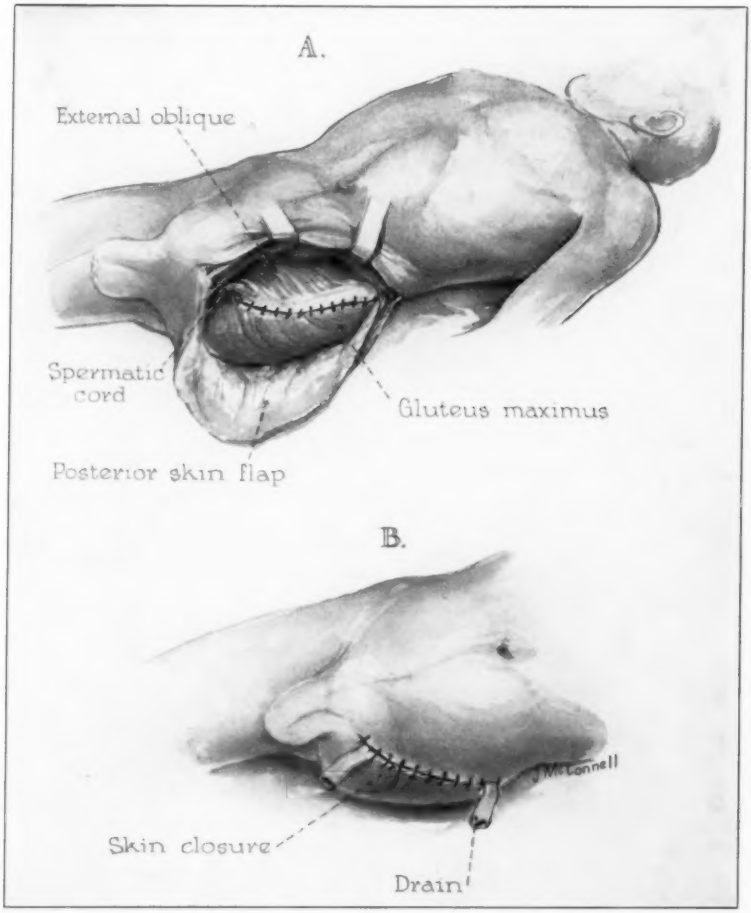

FIG. 5

The shape and location of the skin flap is dictated by the size and location of the lesion as well as by the condition of the skin. The location of the skin incision is secondary to the primary purpose of the operation—complete eradication of the lesion—even though the skin flaps may later undergo necrosis and require replacement.

The posterior skin flap is developed as far back as the sacrum, and is deepened through the subcutaneous fat to the deep fascia. It is then raised enough, posteriorly, for easy access to the sulcus glutaeus between the glutaeus maximus and the glutaeus medius. This groove or fold can be located by palpation.

The glutaeus maximus is separated by sharp dissection from the glutaeus medius and the fasciae latae to the depth of the greater trochanter. There the glutaeus maximus is isolated and transected (Fig. 3,*B*). The muscle is mobilized by blunt dissection through the loose areolar tissue between it and the deep structures, and is retracted posteriorly. All vessels and nerves entering the glutaeus maximus are preserved (Fig. 3,*C*). The authors retain the glutaeus maximus whenever possible because it restores symmetry to the buttocks and, at the same time, fills in the large defect in the pelvic parietes.

Looking from above, the following muscles are now exposed in the posterior wound:

the glutaeus medius, the piriformis, the obturator internus with the superior gemellus above and the inferior gemellus below it, and the quadratus femoris (Fig. 3,*C*). The superior gluteal artery emerges from the greater sciatic notch proximal to the piriformis, and all branches are ligated except those which supply the glutaeus maximus. Distal to the piriformis will be found the inferior gluteal nerve and artery. These are also preserved since they are the principal blood and nerve supply to the glutaeus maximus.

The sciatic nerve is severed distal to the origin of the inferior gluteal nerve (Figs. 3,*C*, and 4,*A*). The posterior femoral cutaneous nerve is cut near the piriformis muscle. The piriformis, the obturator internus, the superior gemellus, and the inferior gemellus are then transected over a curved instrument and are retracted laterally.

The ilium is next exposed at the sacro-iliac joint preparatory to its being osteotomized (Fig. 4,*A*). The latissimus dorsi and sacrospinalis muscles are detached from the iliac crest, and the anterior portion of the glutaeus maximus and the posterior fibers of the glutaeus medius are raised from the pelvis to expose the ilium anterior to the sacro-iliac joint.

The dissection is carried over the top of the ilium into the pelvis and under the iliacus to the superior margin of the greater sciatic notch. A narrow ribbon retractor protects the pelvic contents as the ilium is osteotomized about one and one-half inches anterior to the posterior gluteal line, or further posteriorly if the tumor is close to the gluteal line.

Posterior Dissection

The patient is placed on his back again, and the drapes are adjusted and reinforced preliminary to the third portion of the amputation. The thigh is held in acute flexion and slight abduction by an assistant while an incision is made crossing under the upper portion of the thigh to join the inguinal and gluteal incisions made earlier in the procedure. The complete incision encircles the haunch (Fig. 4,*B*). The cut is continued down into the deep fascia, and the skin margins are mobilized. Little bleeding is encountered.

The limb is then placed with the heel across the thigh of the sound leg (Fig. 4,*C*). The extremity is forcibly rotated externally so as to pry outward the half of the pelvis which has been separated through the pubic bone and the posterior part of the ilium. This lays open the pelvic area, and affords wide access to the remaining intrapelvic structures to be severed (Fig. 4,*D*). These are the levator ani covered by the superior fascia of the pelvic diaphragm, and the obturator nerve and artery. It will be recalled that the obturator artery and nerve traverse the inner wall of the true pelvis before they disappear through the obturator canal to enter the thigh.

The ischiorectal fossa is identified between the surface of the levator ani and the adjacent wall of the pelvis. The levator ani is severed from its attachment to the back of the pubis and the obturator fascia. The obturator artery is ligated at a convenient level along its course, and the obturator nerve is severed. The psoas muscle is transected distal to the point where it enters the pelvis. The femoral nerve, which can now be seen along the lateral surface of the psoas muscle, should be cut at this time if it was not cut in the first part of the operation. The lower extremity is further externally rotated, and the sacrospinalis and sacrotuberous ligaments are cut. The limb, attached to the half pelvis, is now free and can be removed. Bleeding is controlled and loose tissues debrided.

The wound is closed by suturing the margin of the glutaeus maximus and its overlying fascia to the margin of the inguinal ligament and the cut edge of the lateral abdominal wall (Fig. 5,*A*). If the glutaeus maximus has been sacrificed, there will be available only skin, subcutaneous tissue, and deep fascia for the closure of the wound. Penrose drains are inserted to the depth of the wound, and are allowed to protrude through the anterior and posterior extremities of the closure. In some cases, a third drain may be brought out through a puncture wound in the posterior flap for dependent drainage. The skin is closed. A pressure dressing is applied and the purse string around the anus is removed. If the patient is male, the penis and scrotum are released.

The patient is mobilized as quickly as possible following the operation. Ambulation on crutches may be allowed on the second or third day if the patient's condition permits. The in-dwelling catheter is removed after control of the bladder has been regained. A low-residue diet will facilitate control of the bowel and avoid soiling the dressings. The sutures are removed at the end of the twelfth day, and the drains are gradually shortened until about the end of the second week, when they may be completely eliminated. The prophylactic use of antibiotics will minimize the incidence of infection. In most instances, the patient can be discharged from the hospital at the end of the third week.

Hemipelvectomy is a major amputation, justified in specified, stringent cases. The operation is safe if massive blood transfusions are used during the operation to prevent shock, and the surgeon has the necessary basic knowledge of the anatomy and the technique of the operation. Patients can frequently be fitted with an adequate prosthesis, and many will return to a productive life.

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Boat-Nail Fixation of Tendons and Ligaments to Cancellous Bone

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The purpose of this report is to describe a serrated boat nail (Fig. 1), used to attach tissues of small thickness, such as tendons and ligaments, and avulsed cancellous bone fragments to cancellous bone.

Although initially a smooth nail was employed, this was abandoned, because in a few cases the nail became loose as a late complication and had to be removed. The serrated wedge-shaped nail is driven into cancellous bone without previously drilling a hole. The fixation is made secure by the compression of the cancellous bone against the nail and by placing the nail in such a fashion that the direction of the pull of the attached tissues is

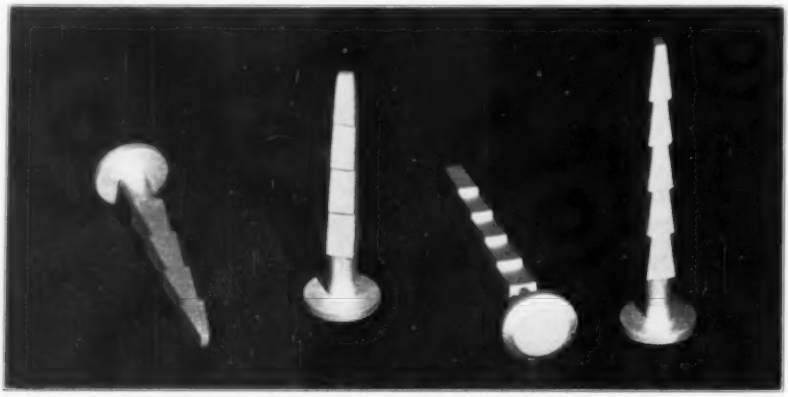

FIG. 1

Boat nails. (Reproduced by permission from *The American Journal of Surgery*, **91**: 739, 1956.)

FIG. 2-A

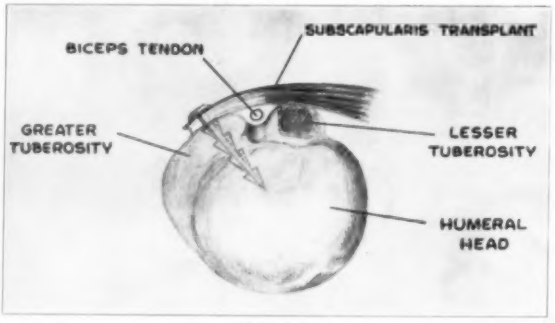

FIG. 2-B

Authors' adapted Magnuson repair operation for recurrent shoulder dislocation showing use of serrated boat nail. (Fig. 2-B is reproduced by permission from *The American Journal of Surgery*, **91**: 739, 1956.)

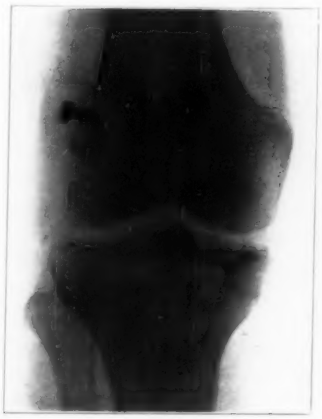

FIG. 3

FIG. 4

Fig. 3: Author's method for repair of laxity of collateral ligament of knee joint by proximal advancement of origin of collateral ligament and fixation by serrated boat nail.

Fig. 4: Reattachment of avulsion of tip of fibular malleolus by use of boat nail (plain).

FIG. 5

FIG. 6

Fig. 5: Replacement of displaced posterior acetabular lip and fixation thereof by boat nails (plain).

Fig. 6: Transplant of anterior tibial tendon in adult, tendon apposed to raw bone and transfixion wire anchored on distant subcutaneous boat nail (subsequently removed).

either perpendicular or at less than a right angle to the long axis of the nail (Figs. 2-A and 2-B). The nail is not suited for use in cortical bone.

There are various uses for the nail.

A heavy aponeurosis may be nailed directly to cancellous bone. Thin fascia or aponeurosis, however, may tear away from the nail unless the free edge is whip-stitched with stainless-steel wire distal to the point of insertion of the nail.

A cancellous fragment of bone can be readily secured if it is large enough to contain the nail and thin enough so that it is penetrated by the cylindrical part of the nail adjoining the head (Fig. 1).

Tendons may be securely attached to cancellous bone with a boat nail by weaving a wire through the tendon and fastening this to a nail which has been previously driven into the bone. Eventual fixation of the tendon to bone is assured if the tendon is so placed that its end is in contact with a roughened area of the bone. If a tendon is narrow, a bone tunnel may be constructed and the tendon pulled through this by means of the stainless-steel wire previously woven through the tendon. The tendon can then be held in position

with ease by securing the wire to a boat nail which is driven into the bone in a convenient place close to where the wire makes its exit from the bone tunnel. Although the wire ultimately breaks into fragments, fixation is maintained long enough to allow the tendon to become fixed to the bone. A tendon of small diameter should not be transfixed by a nail. This will not furnish a secure attachment.

When the nail is driven into the bone, it should be so directed that its long axis forms an acute angle with the direction of the pull of the soft tissues in order to prevent the nail pulling out. The nail should not be countersunk into the cancellous bone as both cortices are needed to sustain the nail. The smallest practicable amount of wire should be used because the combination of two metals of diverse origin may cause an unfavorable tissue reaction.

Approximately 400 smooth and 100 serrated boat nails have been used for the fixation of the anterior capsule and subscapularis tendon in a modified Magnuson procedure used by the author in the treatment of recurrent dislocation of the shoulder; for the fixation of tendons to bone; for the fixation of the humeral condyles after fracture or surgical exposure; for the fixation of a collateral ligament of the knee avulsed at its point of attachment; for the advancement of a collateral ligament in the knee; for the fixation of a fractured malleolus; for the replacement of an avulsed greater tuberosity of the humerus; and for the fixation of tendon transplants about the knee. In all instances good fixation was obtained and was maintained until sound healing had occurred. Three of the smooth nails became loose as a late complication and had to be removed. In spite of this, fixation was not lost. None of the serrated nails have come loose. No evidence of reaction about the nails was noted during the period of observation which was approximately eight weeks. In some cases when excessive amounts of stainless-steel wire were used, there was some foreign-body reaction in the soft tissues and impairment of healing. There were no infections associated with the use of these nails.

Boat-nail fixation is a simple and secure method of attaching aponeuroses, tendons, and small cancellous bone fragments to cancellous bone providing judgement is used regarding the dimensions and physical properties of the tissues (Figs. 3, 4, 5, and 6).

A Bandsaw for Cutting Thin Tissue Sections

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Experiments have indicated the value to science of a new type of microtome, one which is capable of cutting thin sections of fresh gross anatomical specimens including bone, without the necessity of decalcifying the bone before cutting. Accordingly, an apparatus of this sort has been constructed and tested. It is shown in Figures 1, 2-A and 2-B.

The cutting tool is a bandsaw operating in a vertical plane. After experimentation, it was found that a speed of 8.3 feet per second was suitable and that a blade 0.010 inch thick operated effectively, although thinner blades could be used. Fine saws were used at first, but later it was found that saws with eight teeth per inch, which are relatively coarse, cut smoothly enough so that good photographic results could be obtained of the sections.

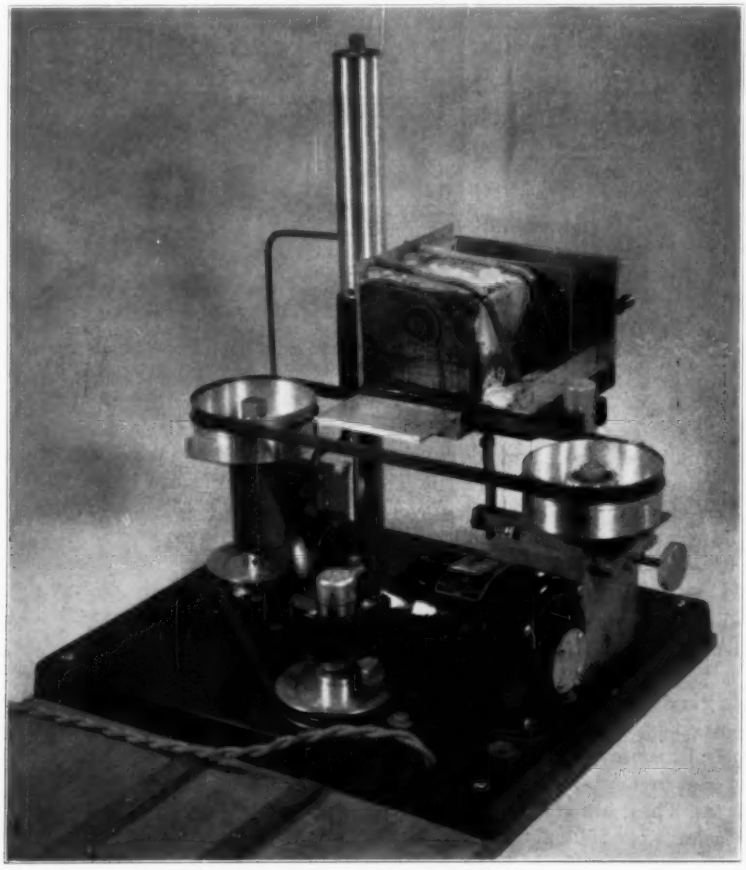

FIG. 1

The apparatus. Specimen is mounted under the springs in the foreground.

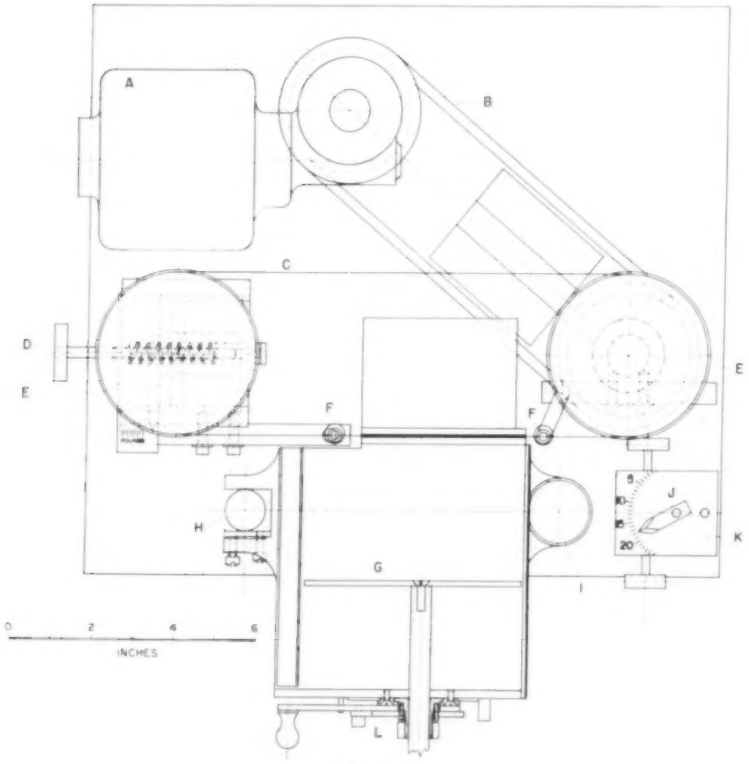

FIG. 2-A

Fig. 2-A: Drawing of the apparatus, top view. *A*, motor, 0.1 horsepower Bodine, 0.1 reduction; *B*, V belt drive; *C*, saw, optimum speed 500 feet per minute; *D*, saw tension adjustment; *E*, saw pulley; *F*, saw guides; *G*, specimen held here; *H*, rod; *I*, hydraulic piston rod; *J*, cutting speed adjustment; *K*, dash pot control valve; *L*, mechanism for advancing specimen.

The tension on the saw can be adjusted by means of a spring which acts on one of the aluminum pulleys. Fifteen pounds tension has been found adequate to assure that the saw will not get out of line during a cut. The saws are set and a saw blade 0.010 inch thick cuts a scarf of about 0.014 inch.

The fresh gross specimen is immersed in water and is frozen into a rectangular block of ice without prior treatment. The block is then mounted on a holder. An oil dash pot is provided so that the specimen descends slowly as the cut is made, the rate of descent being adjusted by a valve. About one minute is sufficient to cut a section four inches square. A ratchet advances the specimen between cuts.

It is very important to maintain a fine section intact after cutting, for sections involving a variety of soft tissues and bone tend to break into fragments. This is done by the same method used heretofore in cutting frozen sections on an ordinary microtome for pathological diagnosis[1,2]. In current methods, a gelatinized film is used to hold sections together and prevent distortion. With the bandsaw it has been found preferable to use glass plates. These are given a thick coating of gelatin, fifteen grams of ordinary photographic gelatin per 300 cubic centimeters of water being used. This is hardened slightly with ten cubic centimeters of a saturated solution of potassium alum. The plates are dried, and a supply is kept ready for use.

In making the section, the specimen is first cut to get a smooth surface at the desired

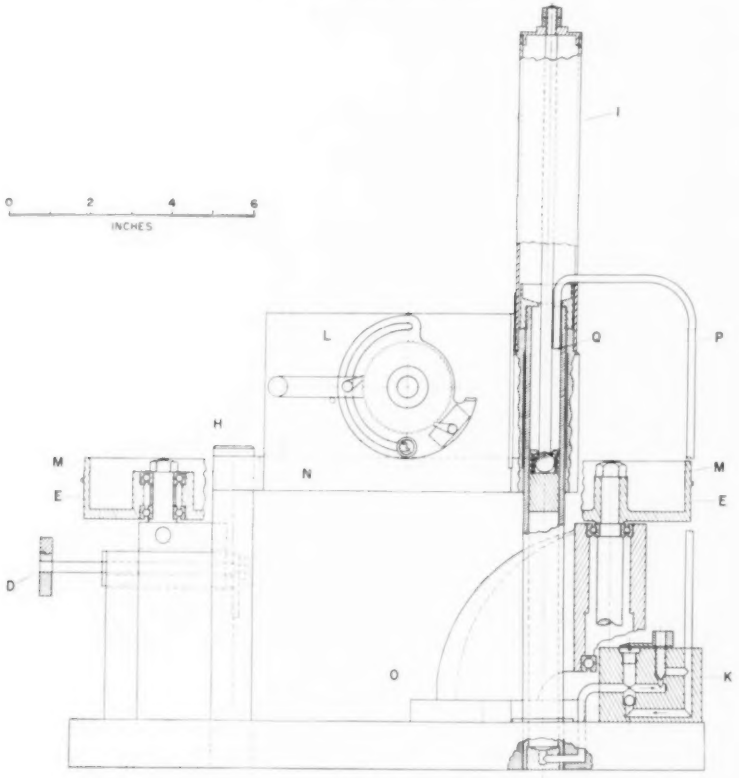

FIG. 2-B

Fig. 2-B: Drawing of the apparatus, side view. *D*, saw tension adjustment; *E*, saw pulley; *H*, rod; *I*, hydraulic piston rod; *K*, dash pot control valve; *L*, mechanism for advancing specimen; *M*, saw position around pulley; *N*, specimen rests on table *N* and gravity lowers it to level *O*, riding down piston *I* and aligned by rod *H*; *O*, lower level of specimen holder; *P*, hydraulic fluid bypass; *Q*, hydraulic dash pot.

location. A coated glass plate is then immersed in warm water at about 45 degrees centigrade for thirty seconds. Surface water is sponged off, and the plate is pressed against the face of the specimen. When this is done the gelatin freezes and the plate adheres securely to the specimen. The cut is then made, the saw passing through the specimen close to the gelatin. The section, still frozen to the plate, is removed and photographed.

It is necessary that the saw be kept at low temperature during the cutting. The blade must be cold enough to prevent thawing of the specimen and block, yet warm enough to make sure that the sections, as they are cut off, have no tendency to freeze to the saw and clog its teeth. The temperature found to be the most effective is slightly below 10 degrees centigrade which, in experiments, was maintained by the simple expedient of cooling the apparatus by placing it in an uncovered box containing a few pieces of solid carbon dioxide.

Serial sections can be made by means of the process described. One millimeter sections, which seem to be thin enough for most purposes, have been cut without difficulty. Thinner sections can undoubtedly be made.

It is desirable to photograph the sections immediately after cutting them. Good photographs can be made, both while the section is still frozen and after it has thawed; the various tissues reproduce readily in natural colors without staining.

In collaboration with Dr. Theodore Winship, Garfield Hospital, Washington, D. C.,

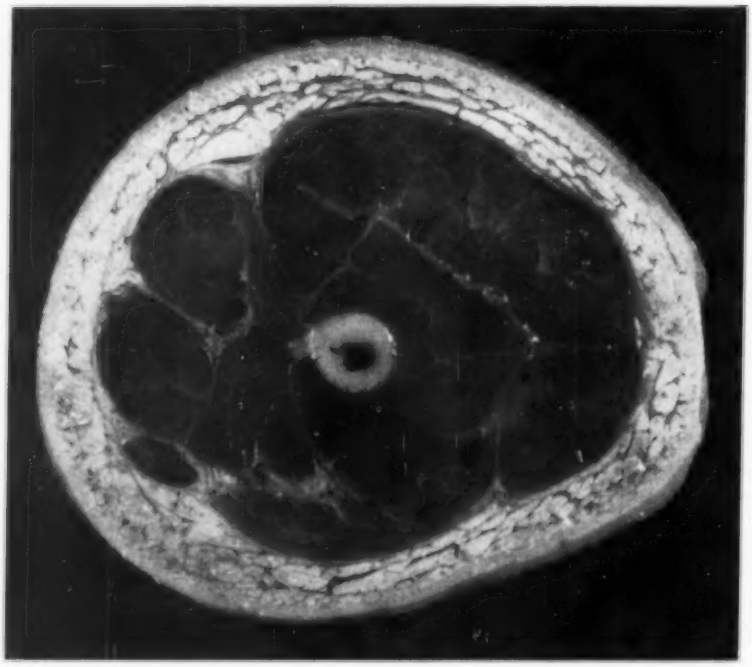

FIG. 3

Fig. 3: Cross section through the mid-thigh of a thirty-eight week human foetus. No distortion is seen in either bone or soft tissue. The muscle hemorrhage is due to a difficult delivery.

the apparatus has been used for various purposes. Figure 3 shows a section from a human foetus.

NOTE: The author is indebted to Mr. W. F. Steiner, Mr. L. A. Horton, and Mr. R. E. Hewitt for their collaboration in working out the many mechanical problems encountered in this research.

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Simple Device for Constant, Slow Instillation of Small Quantities of Fluid

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Numerous recent articles cite the use of antibiotic and proteolytic agents instilled directly into infected or necrotic cavities by means of polyethylene tubes, with or without surgical débridement. Catheters placed into the depths of such cavities at the time of surgery following sequestrectomy have been recently used to administer penicillin and crystalline trypsin directly after operation.

There are also numerous accounts of good results in enzymatic débridement of infected cavities with trypsin or streptokinase and streptodornase without surgery.

The author has had several gratifying results in "drying-up" old osteomyelitic lesions without surgery by means of crystalline trypsin transported in solution to the depths of the draining sinus by a fine polyethylene catheter. In all cases the enzymatic instillation was continuously maintained over periods of forty-eight to seventy-two hours and augmented by systemic antibiotics.

The treatment of infected cavities with trypsin powder contained in gelatin capsules introduced through the sinus has been described. However, the author has found the catheter method much superior in both effect and ease of administration. As stated by Miller, White, and Long, "The catheters provide a method of putting the active agent where it is needed most." The disadvantages of the capsule method are enumerated as follows: (1) many cavities have narrow openings that make the insertion of a capsule difficult or impossible; (2) crystalline trypsin is at its full activity only when dissolved in the proper buffer solution; (3) capsules are time-consuming to fill; and (4) the capsules must be inserted by a physician every three hours in order to obtain maximum activity. The result is around-the-clock disturbance for the patient and medical personnel.

The slow, constant, instillation of a small quantity of any fluid into a cavity presents problems. In the use of crystalline trypsin in osteomyelitis the situation is complicated by the small capacity of the cavity for additional fluid, the expense of the medicine, and by the fact that the enzyme deteriorates in a short time. "The time element is of importance. When allowed to stand at room temperature, trypsin loses 75 per cent of its activity in three hours" [2].

As osteomyelitic cavities are of small capacity and the catheter takes up additional room, the administration must be very slow or much of the active agent will be lost through a back-wash around the catheter. Likewise, in order to get sufficient agent into the cavity to be effective, the flow must be constant. As the costly solution will be deactivated in three hours only a small amount of solution can be employed. Owing to these factors and the additional requirement of a relatively high pressure to overcome the resistance afforded by the fine catheter (especially as its mouth may be butted against the side or floor of the cavity), gravity has been found to be an unsatisfactory motivating force for a reliable flow. When employing a costly material, a minimum of dead space in the form of tubing and complete emptying of the container are desirable.

These problems were solved by use of a simple device (Fig. 1) operated by the resistance offered by a fine gauge (No. 26) needle to the flow of mineral oil or any other available material of high viscosity to the compression produced by stretched rubber bands. Two ten-cubic-centimeter syringes, filled with mineral oil, with No. 26 needles attached are coupled with a third ten-cubic-centimeter syringe containing the solution to be instilled.

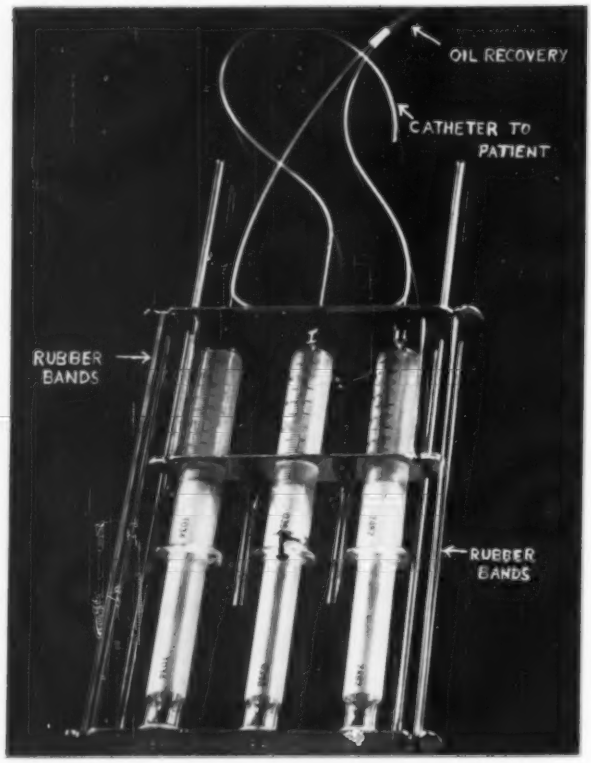

FIG. 1

This is done by placing the needles and barrels of the three syringes through holes in a metal frame which is coupled with a sliding bar against the protruding ends of the pistons. The syringe containing the active material is placed between the two containing the mineral oil. Pressure against the pistons of the syringes is afforded by rubber bands stretched from the frame to the bar against the pistons. The syringe containing the medicinal solution empties at the same slow, constant rate as those containing mineral oil.

The rate of flow can be varied by using either smaller or larger needles on the lateral syringes or by adding more or stronger rubber bands. The fine needles on the syringes containing the oil are introduced into a loop of polyethylene catheter, the two ends of which are placed in a vessel to recover the oil.

Crystalline trypsin in solution will maintain nearly its full activity for about two days under refrigeration. The entire device was successfully operated while submerged in a pan of icewater. It is thus to be expected that the last drop to be instilled had nearly the same potency as the first.

Two legs were fixed to the frame to lift the bar against the end of the pistons above the table which prevents drag and extra work for the rubber bands. Additional stability is afforded by drilling circular concavities in the pressure bar to accommodate the ends of the pistons. The apparatus can easily be loaded by the nurse, and only reasonable care is required to fill the syringes with approximately equal amounts of liquid because all three will even out in the first few minutes of operation. The device can also be used for the slow, constant injection of small amounts of antibiotic material into joint cavities in the treatment of pyarthrosis.

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The Role of the American College of Surgeons in the Treatment of Fractures

BY W. L. ESTES, JR., M.D., BETHLEHEM, PENNSYLVANIA

The early interest of the American College of Surgeons in the field of trauma was the direct result of investigations in the treatment of fractures conducted by a senior organization in surgical society ranks—the American Surgical Association. As early as 1891, this organization of representative surgeons of Canada and the United States became interested in successful end results in treatment of fractures of the femur, which, with the imperfect methods of therapy then in use, presented a great challenge.

The discovery of the x-ray by Roentgen in 1895 accelerated and widened study in this field. By 1900, the American Surgical Association reached the conclusion that treatment of femoral fractures, as practiced at that time, left much to be desired. Further stimulation of the search for better methods of fracture therapy was the visit of Sir Arbuthnot Lane to the United States in 1909. By that time, his method of fixation of fractures by metal plates and screws was well established.

In 1911, the Presidential Address delivered by Dr. Richard H. Harte at the Annual Meeting of the American Surgical Association dealt with the treatment of fractures. As a result of the interest aroused by this address, a symposium on fractures was held at the Annual Meeting the following year, and, by resolution, the President was authorized to appoint a committee of five to study the relative values of operative and non-operative treatment of fractures of the long bones, and the value of roentgenography in determining the best methods of treatment.

This committee consisted of Dr. John B. Roberts, Philadelphia, Pennsylvania, Dr. William L. Estes, Bethlehem, Pennsylvania, Dr. Thomas W. Huntington, Los Angeles, California, Dr. Edward Martin, Philadelphia, Pennsylvania, and Dr. John B. Walker, New York, N. Y.

Efforts were made by the Committee to ascertain, through questionnaires sent to the Fellows of the Association, records of end results in the treatment of fractures. The result was disappointing, however, because of the few adequate records obtainable for study.

In 1914, Dr. Roberts was replaced by Dr. Astley P. C. Ashurt, of Philadelphia, Pennsylvania, and the work of the Committee to secure factual information was continued with Dr. William L. Estes, of Bethlehem, Pennsylvania, as Chairman. The 1921 report of the Committee—which was to be its final one—summarized its conclusions as to the treatment of fractures of the long bones, and stressed the fact that the purpose of the Committee's work was defeated by the unavailability of adequate data because of deficient record-keeping.

The majority of members of the American Surgical Association were also members of a younger organization, the American College of Surgeons, which had been founded in 1913. Its major objectives were the betterment of hospital care and equipment and of teaching facilities in medical schools and hospitals, the establishment of acceptable minimum standards, and the formation of an inspection system by which hospitals could be rated. It was the opinion of the Committee that the American College of Surgeons was in a better position than the American Surgical Association to bring into general use an improved system of record-keeping and to take up cudgels for better fracture therapy.

It seemed logical to discontinue the Association's Fracture Committee and to approach the American College of Surgeons concerning the need for better fracture therapy and the necessity for the accumulation of reliable data on which to base new theory and improved practice.

The proposal apparently fell upon sympathetic and cooperative ears, for it is recorded that at a meeting of the Board of Regents of the American College of Surgeons in May 1922, a Committee on Fractures was appointed with Dr. Charles L. Scudder of Boston, Massachusetts, Chairman, and Dr. John B. Walker of New York City, Secretary.

The members, in addition to Dr. Scudder and Dr. Walker, were Dr. Nathanial Allison of St. Louis, Missouri, Dr. Astley P. C. Ashurst of Philadelphia, Pennsylvania, Dr. Joseph A. Blake of New York City, Dr. Frederic J. Cotton of Boston, Massachusetts, Dr. William Darrach of New York City, Dr. William L. Estes of Bethlehem, Pennsylvania, Dr. W. Edward Gallie of Toronto, Ontario, Canada, Dr. Fraser B. Gurd of Montreal, Quebec, Canada, Dr. George W. Hawley of Bridgeport, Connecticut, Dr. August F. Jonas of Omaha, Nebraska, Dr. Paul B. Magnuson of Chicago, Illinois, Dr. Lloyd Noland of Birmingham, Alabama, Dr. Robert B. Osgood of Boston, Massachusetts, Dr. William O'Neil Sherman of Pittsburgh, Pennsylvania, Dr. Ernst A. Sommer of Portland, Oregon, and Dr. Kellogg Speed of Chicago, Illinois.

Three of these men, Ashurst, Estes, and Walker, had been members of the 1921 Fracture Committee of the American Surgical Association; through these members continuity of effort was maintained.

A further stimulus to the establishment of a Central Committee on Fractures by the American College of Surgeons was the accelerated interest in fracture therapy as a result of World War I. During the War, the best surgical minds of North America and Europe were concentrated on the surgery of trauma, and had hastened the establishment of new fundamental principles and methods of treatment of fractures. At the same time, the mounting toll of accidents under modern living conditions and particularly the severity of injuries due to automobile casualties were influencing study and research, and new methods of fracture therapy were being evolved.

It was anticipated that end results of fracture treatment would be ascertained by the assembly and study of thousands of records of fracture cases which would be available, eventually, through the requirement of the American College of Surgeons for detailed record keeping.

During this formative period the Committee recommended that there be added to minimum standards for hospitals (1) the setting up of standards for minimum equipment for the treatment of fractures to be required of every approved general hospital and that one surgeon be responsible for the supervision of the care of fractures; (2) the declaration of principles which underlie first aid and emergency treatment of fractures and the institution of an active educational campaign for their use; (3) the determining of minimum equipment necessary for the transportation of patients with fractures; (4) uniform standards of teaching the surgery of trauma in medical schools; (5) the statement of principles for the definitive treatment of fractures and the keeping of records on especially designed fracture record sheets; and (6) the standardization of bone plates and screws. The Committee emphasized the need for interesting other organizations in modern treatment of fractures—the American Medical Association, The American Red Cross, the American Railway Association, and the Boy Scouts of America to name but a few.

At the suggestion of Dr. Franklin Martin, an Annual Oration on fractures at the Clinical Congress of the American College of Surgeons was established.

Regional committees were established with each member of the Central Fracture Committee acting as chairman of a regional group. At the local level, the regional committees served as forums for the discussion of fracture therapy and for postgraduate education; they also supplied the means by which programs of the Central Fracture Committee were circulated widely throughout the country.

Programs were planned for the presentation of various phases of the subject of fractures at every Sectional Meeting of the American College of Surgeons.

Subcommittees were appointed to develop various fields of operation for the Central Fracture Committee. These were concerned with minimum standards of hospital equipment; transportation and emergency treatment of fractures; education concerning fracture treatment at both graduate and postgraduate levels; splints; the study of end results in fracture therapy; and the formation of regional committees.

As time went on, further subcommittees were appointed to investigate the use of the fluoroscope in fracture therapy, for liaison with the Red Cross to aid in the revision of the Red Cross first aid textbooks, for liaison with the National Safety Council and the American Railway Association, for study of standards in brace and artificial limb prosthesis with the Association of Limb Manufacturers, and for the development of the use of motion pictures in the study of fracture therapy. The first of these films was authorized in 1928. Relations were formed with industrial and labor organizations and with insurance carriers and government agencies; basic principles were agreed upon for the rehabilitation of the injured. Plans were formulated for coping with mass casualties in the event of major disaster and for traffic safety.

During the early days of the Central Fracture Committee, authoritative articles were presented from time to time by the members. These were collected, and in 1931 were published as *Illustrated Primer on Fractures* which described the principles and technique of good fracture treatment. The pamphlet proved to be so popular that a second edition was printed in 1932, enlarged in 1933, and reprinted again in 1938. Twenty-four thousand of the first two editions alone were sold. A third revised edition was published in 1940 and a fourth edition in 1942. There were three printings in the following seven years. By 1949, the pamphlet had reached the dignity and character of a manual, and in 1950 the international demand for copies almost equalled the demand for them in Canada and the United States. The most recent revision was in 1954.

The Annual Meeting of the Central Fracture Committee has always been held in January or early February at some medical center. The first day is devoted to clinical demonstrations of fracture or trauma therapy, and at dinner in the evening very free and frank discussions of the day's program take place. The second day is given over to an executive session, which includes action on the reports of the subcommittees.

From the early days, members and officers of the Central Fracture Committee have met with the Regional Fracture Committee at each Sectional Meeting in order to discuss organizational problems. Fracture exhibits have been authorized at state medical society meetings. In 1929, a committee was appointed with Dr. Kellogg Speed of Chicago as chairman to act in liaison with the American Medical Association in the preparation of a fracture exhibit or demonstration for each American Medical Association meeting. Dr. Speed continued as Chairman of this Committee until his death in 1955. He has been succeeded by Dr. Ralph Carothers of Cincinnati.

The Minimum Standards Requirements have been reviewed from time to time, changed materially in

1940, and completely rewritten in 1950. The impetus to the movement toward better fracture therapy as a result of this one action of the Fracture Committee has been tremendous.

The membership of the Central Committee has increased gradually to include representation from all parts of Canada and the entire United States. In 1932, there were forty members. Today there are forty-five active members of the Committee and ten members emeritus.

Dr. Scudder resigned the chairmanship of the Fracture Committee in 1933; he was succeeded by Dr. Fred Bancroft of New York. In 1939, the Committee on Fractures was incorporated with the Committee on Industrial Medicine and Traumatic Surgery, which had been independently active since 1919. Dr. Robert Kennedy assumed the chairmanship of the combined committee, which was designated as the Committee on Fractures and Other Trauma. In 1949, the name was changed to the Committee on Trauma, and in 1952, Dr. B. Arnold Griswold became Chairman.

In recent years the regional committees have been organized into sectional groups, greatly increased in numbers and with a chief in each section. There are, now, 126 committees with a membership of over 2,450. In 1952, a brochure on the objectives and organization of the regional groups was issued and widely distributed.

The Subcommittee on Education has maintained active liaison with the Council on Medical Education and Hospitals of the American Medical Association, the Association of American Medical Colleges, the Commission on Medical Education, and the Committee on Teaching of Surgery of the American Surgical Association, in order to improve both undergraduate and postgraduate instruction in fracture and trauma treatment. It has recently completed a survey of the methods of present-day teaching of the treatment of trauma in medical schools.

Bulletins on hand and head injuries have been approved and distributed to the regional groups, and *A Manual on Trauma of the Soft Tissues*, edited by Dr. Michael L. Mason, was published in 1954.

Twenty-three Annual Orations on fractures or trauma have been delivered.

Postgraduate courses in fracture therapy have been offered to the membership at the last three Clinical Congresses.

SUMMARY

It is obvious from this very brief summary the far-reaching impact, the wide spheres of influence, and the stupendous role that the American College of Surgeons has played in the development of better therapy of fractures and in the rehabilitation of the injured.

The primary approach has been simplification, not standardization, of treatment and the establishment of principles by which the treatment of fractures and other traumata may be continually improved.

The College's fundamental concept of the surgeon's responsibility to his patient has been emphasized repeatedly, that in good fracture care the surgeon's duty to the injured person goes further than simply to see that he is properly splinted and transported from the scene of an accident. His responsibility is not fully discharged until, with after-care by a properly trained team and with follow-up treatment, the maximum restoration of function has been obtained.

The great need for more thorough education at undergraduate and graduate levels in the field of trauma has been particularly emphasized, and active liaison has been increasingly established with other organizations which are concerned with the care of the injured, as wider fields in the applications of objectives and techniques have been developed.

It has been said that the successful activities of the Fracture Committee have constituted the greatest contribution made by the American College of Surgeons to the American public and to the medical profession. In the words of Fred Coller: "The Fracture Committee of the American College of Surgeons has accomplished as much to help the injured as any other influence in modern surgery has done."

NOTE: Full acknowledgement should be given to Miss Eleanor Grim, former Secretary of the American College of Surgeons, whose monumental factual compendium of The History of the American College of Surgeons has been the major source material from which this account has been compiled.

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Proceedings

AMERICAN ORTHOPAEDIC ASSOCIATION

Annual Meeting 1956

For the Sixty-ninth Annual Meeting of The American Orthopaedic Association the members journeyed far and high to Banff, Alberta, in the Canadian Rockies. The meetings were held on June 20, 21, 22, and 23 under the genial guidance of President Paul C. Colonna.

The Association welcomed distinguished guests from abroad in the persons of Dr. Jean Verbrugge of Belgium, Prof. Ryosuke Katayama of Japan, Dr. H. J. Seddon of England and the British Exchange Fellows. These latter, whose picture among the aborigines appears on this page, reached Banff after a six-weeks' tour of medical centers across the continent, up the Pacific coast and in Western Canada. The address made

Photograph of the Commonwealth Exchange Fellows made while they were being entertained at the home of Dr. Ernest Burgess, Seattle, Washington. From left to right the exchange Fellows are John Golding, Mana St. Andrew, Jamaica; David Evans, London, England; O. R. Nicholson, Aukland, New Zealand; Anthony Quinlan, Glasgow, Scotland; and John Sharrard, Sheffield, England.

at the Annual Banquet by their spokesman, Mr. D. L. Evans, will be remembered and the report of their experiences and observations will be looked forward to.

As in other years the scientific and executive sessions occupied the mornings, leaving the rest of the day for informal discussion and the communion of kindred spirits. The thoughtful planning of the Chairman of the Ladies Committee, Mrs. William T. Green, helped the attending ladies to forget their distaffs.

Not on the Agenda were the vicissitudes of certain eastern members on their journey home, in the course of which they may have thought of the Donner expedition without, happily, reaching that dire extremity.

The meeting cannot be properly described without a bow to Mother Nature. Members will be explaining for years to come that the background of the group picture is real.

The members elected at the 1955 meeting of The Association were presented at the President's Reception on Wednesday evening.

(Continued on page 1175)

The Evolution of Physiological Concepts in Bone Surgery *

BY PAUL C. COLONNA, M.D., PHILADELPHIA, PENNSYLVANIA

An orthopaedic surgeon may well be proud of the great privilege of being your President. As our group represents the oldest active national orthopaedic association in the English-speaking world, this honor, as one Past President so wisely wrote me, "will make you proud, happy, humble, and inspired all at one time"—although I doubt the latter quality has been achieved. It has been a memorable year in the life of your President, and he would like to express to you his many thanks for the friendly letters and messages received by him. Needless to say the duties have been made pleasant and the responsibilities lessened by the unfailing efforts of your officers and committee chairmen and of your indefatigable secretary, to all of whom I owe a vote of sincere thanks.

For some years your President has felt the desire and hope that someone in The Association would have the temerity to make a plea for better physiological concepts in bone surgery. Today I would like to try to discuss this subject, which in the past few years has been increasingly in my thoughts.

I know that we all see the need in our daily practice for better physiological concepts regarding bone surgery. I know that we all try to keep constantly in mind basic principles when repairing bones. The rigid framework of our body supplies strength and support. Yet, our surgical techniques must be based on sound physiological grounds and bone must not be thought of as an inanimate, rigid type of substance in which substitutions can freely be made for missing or poorly functioning parts.

We must not lose sight of the lessons the past can teach us, for to be unfamiliar with the past may result in a duplication of effort and needless surgery for the patient. It is always helpful and instructive to browse among books that reveal the thoughts of the great masters of our specialty in their indefatigable search for information regarding the phenomena of tissue growth and repair as illustrated in bone surgery. The accumulation of knowledge is at best a slow process requiring both experience and observation. Today basic investigations of the osseous system have possibly lagged behind the study of many of the other systems, due to the lack of zeal on the part of those most intimately concerned, the orthopaedic surgeons. Regarding the importance of investigation, it may be of interest to quote from the third American Orthopaedic Association presidential address by Dr. E. G. Brackett in 1899. He wrote, "Investigation is *especially* needed as well as the careful collection of recorded facts and results"; more than half a century later, we are seeing the fulfillment of this goal through the newly organized Orthopaedic Research Society and its financial ally, the Orthopaedic Research and Education Foundation. These two organizations should succeed in establishing orthopaedic surgery on a more scientific foundation, and we believe in and foresee their growth and contributions as vital factors in our specialty. Let us also remember that medical advances are frequently made through ancillary contributions and by non-medical as well as medical observers, so that it behooves each of us to keep in contact with investigators in related fields. The broad scope of the membership eligibility in the newly organized Orthopaedic Research Society should be of great educational value to the specialty of orthopaedic surgery; it is felt that the work of this Society will help to prove the truth of the statement that "progress is our most important product".

The early founding of our Association in 1887 and the consistency with which scien-

* Presidential Address read at the Annual Meeting of The American Orthopaedic Association, Banff, Alberta, Canada, June 22, 1956.

tific investigation was stressed in the earlier of our presidential addresses make us realize that scientific curiosity has been and must always be our guiding star. In 1900 there were fifty-one members in this Association, of whom twenty-six were engaged in teaching. Today our active membership is 150, of whom 75 per cent are actively affiliated with a teaching institution. This means that The American Orthopaedic Association is largely made up of men who have access to facilities for investigative work. With the stimulus of coordinated effort we may expect more fundamental information regarding basic bone physiology to be forthcoming.

In the recorded history of medicine, we early find reference to the bony skeleton. Hippocrates (460-ca. 377 B.C.) devoted a good deal of his written lectures to the treatment of dislocations and fractures. A look back through the evolution of medicine reveals that in every period there have been outstanding figures interested especially in bone surgery.

The seventeenth century has been called the age of individual scientific endeavor and in this period are found the brilliant lectures of William Harvey (1578–1657) on the blood and its circulation and the contributions to the knowledge of structure by that great microscopist, von Leeuwenhoek (1632–1723). In the realm of surgery, however, the contributions of this period were very meager. Richard Wiseman (1622–1676) of England and Hendrik van Deventer (1651–1724) of Holland were possibly the foremost men in this field, the latter practicing orthopaedic surgery in his native city, The Hague, until his death twenty years before Nicholas André (1658–1742) published his *Orthopaedia* in 1741. The next century was the age of theory and systems, but still the contributions toward a greater knowledge of bone growth and repair were few. In both the seventeenth and eighteenth centuries, therefore, the number of investigators of bone structure was meager; these centuries were great eras of controversy regarding this tissue, however.

The revolutionary development of the study of bone tissue appears to date from an epoch-making observation on madder-stained bone in 1736. Up to this time a great many observations and contributions had been made on the gross appearance of dead bone, but here was an observation on living, growing bone. While this observation was noted and recorded by John Belchier of London (1706–1785), it remained for a non-medical man, a French lawyer, Henri Louis Duhamel (1700–1782), to recognize its significance in relation to bone growth, to glimpse, through repeated experiments on the animals of his farmyard, some facts on the way bone grows, and to theorize on the important part that the periosteum plays in bone growth. The astute, acquisitive mind of this young lawyer was truly scientific, for he preceded his conclusions by observations and experiments. He noted that the long bones grow by layers, these layers resembling the rings seen in tree growth. He noted too that only the *newly* deposited bone was stained red in the madder-fed animals and that he could control the development of these red rings by feeding methods. In a series of animal experiments he drilled holes into the shaft of the bone, filled them with silver stylets, and then noted that all growth in length occurred only at the extremities of the bone and that the drill holes remained the same distance apart after a period of time. Unfortunately, he did not explore epiphyseal growth but concluded that longitudinal growth must occur at the extremities of bone and not in the shaft. It remained for John Hunter (1728–1793) to reveal further facts regarding diaphyseal and epiphyseal growth. Duhamel believed from his experiments that the periosteum was the maternal tissue of bone. This school of thought, which had tremendous sway, was in direct opposition to the beliefs of that great Swiss investigator, von Haller (1708–1777), the teacher of John Hunter. The Hunterian school concluded that bone was not formed by the periosteum but that the arteries, at the ends of the bone far removed from the periosteum, were the true depositors and builders of bone, ossification being the function of the arteries. The periosteum was regarded only as a vascular covering for the nourishment of bone. Despite this erroneous theory, the experiments of John Hunter on bone growth, bone grafting, and the function of muscles are strikingly fresh and ap-

plicable today. When he stated that his aim in the treatment of disease and injury was "to supply to the patient those factors favorable for recovery and remove those that are unfavorable", he was expressing a basic concept in the care of the sick which we can well meditate upon today.

Orthopaedic surgery about this time shifted its center of scientific output from Paris to London, due in large part to the teaching of William Hunter (1718–1783) and his brother, John. There were other outstanding orthopaedic surgeons in Britain, but the greatest development in our specialty at this time was the continuing growth and productivity of the American medical schools. Garrison's *History of Medicine* reports that in 1826 Dr. John Rhea Barton (1794–1871), then thirty-two years of age, performed by open operation the first osteotomy on a patient with ankylosis of the hip joint. This he did in order to achieve motion, for as a result of the patient's daily postoperative movements a pseudarthrosis or movable joint was produced at the site of osteotomy; this has been recorded as the first arthroplasty in America. Dr. Barton received his medical degree from the University of Pennsylvania in 1818 and made many important contributions to surgery, such as the identification of Barton's fracture and the design of Barton's bandages. Twenty years after this first open osteotomy, German surgeons introduced the subcutaneous osteotomy for the correction of deformity.

There were in England and on the Continent, therefore, two schools of thought, the Hunterian and Duhamel schools, based on divergent views regarding the source of bone growth. Hunter's concept has been proved incorrect, but some of his other observations on bone growth have been found more accurate. In his twenty-sixth year he noted that bone has the power to absorb and eliminate a portion of its structure as well as to build itself up; this modeling power, consisting of both deposition and absorption, is now recognized as being characteristic of bone. In an experiment very similar to Duhamel's, John Hunter placed two drill holes in the cortex of bone and filled them with pellets, noting that the growth of the bone at the ends did not change the distance separating the two holes. He also noted that if bristles were inserted into drill holes leading into the medullary cavity and were left in place, the openings became oblique canals which inclined toward the upper end of the tibia where the main epiphyseal growth occurs. This, he claimed, was due to the drag inflicted on the periosteum as the circular layers were deposited, and he felt that it explained the obliquity of the nutrient canals in the bone. These two great investigators, one a physician (Hunter), the other trained not in medicine but in the law (Duhamel), contributed much of the basic knowledge on bone growth that was available in those early years.

Hunter's concept of the modeling power of bone was a forerunner of the concepts that later were expounded in Wolff's law. Julius Wolff (1836–1902) sought to formulate into words a physiological law of bone growth, namely, "that a bone has the power to adapt itself to the burden it has to bear"; this is to say that when stress and strain are placed on a plastic substance, such as bone, the physical shape of the substance is altered in response to these forces. This is not very different from Hunter's concept formulated over a half century earlier.

Another research study on the reproduction of bone by periosteal participation was the striking experiment performed by James Syme (1799–1870) in his thirty-sixth year. He removed portions of the radii of both the right and left forelegs of a dog. On the right he removed the periosteum as well as the bone; on the left, only the bone. The sleeve of periosteum that remained on the left reproduced the radius, but a gap remained on the opposite side. He repeated a number of similar experiments before concluding that the periosteum was a bone-producing membrane.

John Goodsir of Edinburgh (1814–1867), an investigator trained in dentistry, held a contrary view, for he felt that the periosteum does not have the power to form bone. Following the introduction of the microscope into his investigations, he concluded that

the presence of so-called "bone corpuscles", which he had noted in every form of ossification, must be the fundamental explanation of bone growth. He held the office of Curator of the Museum of the British College of Surgeons for only three years but made tremendous contributions during this time. Sir Arthur Keith has stated that Goodsir had "two qualifications which are absolutely essential for the man who would open a new field of knowledge—a new instrument and a fresh inspiration". This man was one of the pioneers of the cell doctrine, the development of which had been made possible by the invention of the microscope. This doctrine led him into many paths of investigation. One of his most far-reaching findings was that absorption was a natural function in every kind of cell, including those which are found in bone. Another finding was that the power of the periosteum to form bone depends wholly on the fact that particles of true osseous substance from the shaft become adherent to it; as a result of this finding he believed that the periosteum is simply a limiting, passive membrane that surrounds and nourishes bone. To him a bone was a hive of "bone corpuscles", a belief which was a forerunner of the modern conception that in addition to minerals which provide rigidity, the bone matrix is made up of osteocytes, collagen fibers, and an interfibrillary cement substance. Today we need more investigative studies on the structure and function of the osteoblast.

Goodsir started out as a firm disciple of John Hunter's teachings regarding the function of the periosteum, but his study of marine forms, especially sponges, convinced him that bone was not deposited by the arteries and was not absorbed and remodeled by the lymphatics, as taught by Hunter. The microscope enabled him to study the Haversian canals and led him to believe that the human skeleton was laid down by separate self-acting units of living matter. The formation and structure of the supporting framework of the body are the result of the activity of the highly specialized connective-tissue elements of bone. Remembering Keith's observation on the stimulating effect of a new instrument combined with inspiration, we may surely expect further basic developments as a result of the use of the electron microscope and as a result of recent studies in the chemistry of blood.

Sixty-five years after Hunter's death, Louis Ollier (1830–1900) came upon the scene. He at first believed that the periosteum has no primary osteogenetic function, but later changed this view as a result of a series of very interesting experiments. In one set of rabbits he raised a tongue-like flap of periosteum from the tibia, leaving it attached at its base and placing it over the deep flexor muscles of the leg. This produced a loop of bone, thick at its base and tapering to a fibrous tip. In another set of animals he twisted a similar piece of periosteum at its base and produced a beaded string of bony nodules. In the third set a completely detached piece of periosteum was transplanted into the subcutaneous tissues. This produced bone, demonstrating that periosteum could be used as a bone-producing graft and thereby convincing him of the osteogenic properties of this tissue. He later discovered that there are osteoblasts in the deepest layer of the periosteum and found that bone shavings serve well as grafts. He, it is said, realized that "experimental physiology is and must be the basis for all rational operations in surgery".

Ollier was a contemporary of Lister (1827–1912), so that we now enter a phase of the experimental study of bones and joints which was made possible by the invention of the microscope and by the dawning of the aseptic era. Ollier found that osteoblasts can be recognized in the deepest stratum of the periosteum and that these cells increase in number following irritation of the diaphysis by injury or suppuration. In his experiments he observed that the grafts from young animals took more readily than those from adult animals and that different animals had different powers of bone formation. Ollier was a most remarkable investigator and proved to his own satisfaction that pieces of living bone which include the periosteum and marrow provide the most perfect form of bone graft. He is one of several famed surgeons who have successfully removed a portion of a diseased humerus by subperiosteal dissection and have showed later that the shaft reformed.

A similar type of resection was done in the famous operation performed by William MacEwen (1848–1924) of Glasgow in 1878 on a child three years of age. He excised almost the entire humerus and in the resulting gap planted a row of tibial grafts which he had removed when performing osteotomies and many of which were devoid of periosteum! A reconstructed humerus six centimeters in length resulted, and about thirty years later this humerus was well formed and useful, demonstrating both the modeling and coalescing properties of bone chips and thereby showing that fragments of bone may be used as grafts and that such grafts will live, grow, and reproduce bone. MacEwen's experimental and clinical observations led him to do many more experiments upon bone growth, as is so delightfully described in his great book, *The Growth of Bone*, published in 1912. His conclusions regarding the role of the periosteum were exactly the opposite of those reached by Ollier, namely, that the periosteum has no power to form bone. He did concede, however, that the deepest strata of the periosteum may be the source of osteogenic power. In 1908 Axhausen published his great work on free bone transplants, noting the adaptation of transplants to their new environment.

This brings us up to comparatively recent times. There are many orthopaedic surgeons who have been or are now members of this organization, who have made outstanding contributions to bone surgery—Lane, Gallie, Robertson, Starr, Hibbs, Phemister, Abbott, Key, and others—but one cannot omit the name of the ingenious and talented F. H. Albee (1876–1945). It was he who, in 1911, initiated the employment of living bone grafts as internal splints and who, by his motor-driven mechanical tools, made it possible for these grafts to be prepared quickly and accurately with almost cabinet precision as to fitting.

We should be guilty of a grave oversight if we did not also stress the great work of two distinguished Canadian members—W. E. Gallie and D. E. Robertson. In 1918 Gallie and Robertson published an outstanding article on the transplantation of bone, pointing out that when a living or autogenous graft is implanted, there is an immediate coagulation of its cells and vessels which produces a barrier which the surrounding lymph is unable to penetrate. As a result of this barrier the osteoblasts in the lacunae die almost at once and many of the osteoblastic cells in the Haversian canals also die. However, there are many osteoblasts which do not die and which absorb the nutriment from the bathing lymph; these cells proliferate on the surfaces of both the endosteum and the periosteum, and at the end of ten days, they can be seen to be attacking the dead bone, as is demonstrated by the presence of excavations in the graft and by a further proliferation of osteoblastic cells. This process is coexistent with the re-establishment of the circulation by ingrowing blood vessels, so that one can see proliferation of the viable osteoblasts going on hand in hand with the process of absorption and modeling.

Gallie and Robertson also pointed out that boiled bone grafts present a very similar pathological picture, but that the whole process is slowed down. Their concept, formulated almost forty years ago, is very much like our present thinking.

These authors stated that the only osteoblasts which survive when heterogenous grafts are used are those which come from the host; they also claimed that porous, not cortical, bone should be used to fill bone gaps and that the latter should be used only when stability is desired. Many practical observations were made by these investigators. They stressed the fact that at times it is advantageous to split the grafts in order to provide a number of surfaces, for in their experimental work they had found that more osteoblasts were seeded on the broad surface of grafts than were seeded elsewhere; we use this method today in preparing the barrel-stave type of graft. Other conclusions of these men were that the grafts should not be too short; that the ever present danger of infection must be constantly in the mind of the surgeon; that in sawing grafts care must be taken so that the heat from the sawing will not cause local damage to the bone; that there must be firm contact of healthy bone between host and graft; and, lastly, that the graft can be transplanted with or without its periosteum, for, from the standpoint of

osteogenesis, the presence of the periosteum appears to make little difference. All of these statements are accepted as fundamental truths in bone surgery today.

In discussing American workers in this twentieth century, we must not omit the tremendous contributions that emanated from the investigations of D. B. Phemister (1882–1951). He advocated the use of split grafts in the treatment of delayed union and non-union of fractures, stating that, "Once a bony bridge is established across a portion of the fracture line, the remaining intermediary callus will ossify, provided the fracture is adequately immobilized and protected from weight bearing." The osteoperiosteal grafts of Dćlangénière, the massive onlay grafts of Henderson and Campbell, the sliding grafts of Haglund, the grafting principles enunciated by Lambotte—all demonstrate basic principles in bone surgery.

The widespread need for fixation of fractures by means of metallic agents and for the prosthetic reconstruction of joints has had an almost over-enthusiastic response, although I detect a lessening of enthusiasm for hip-joint prostheses. The sound physiological concepts that stimulated the contributions of Venable and Stuck and other investigators who have stressed the use of non-toxic, non-electrolytic media, such as Vitallium and other alloys, have all been accompanied by great advances in our specialty. If, however, we turn back to the earlier workers in this twentieth century, we realize that most of their concepts of bone grafting were based on sound physiological principles and that these principles are not always employed today. It is true that the introduction of gadgets has led to many and wonderful impedimenta being placed into the tissues of the body, some of which have unquestionably been of aid in rehabilitation. It is difficult to say when the gadget era of our specialty reared its ugly head, but it is not hard to say why. Firm fixation and correct alignment of fracture fragments encourages rapid healing; therefore, as improvements in the manufacture of alloys and of non-toxic materials increased, devices, with their mechanical advantages, became more popular, a situation which the commercial houses were quick to appreciate. It is to be hoped, however, that today there is a healthy swing away from the wholesale use of gadgets and a return to a more physiological approach to bone repair and to the treatment of irregularities in bone growth. May I call your attention to the fact that Haglund in 1917 made the following interesting observation: "In the remarkable development of bone surgery during the past few years, the most conspicuous feature is that the use of materials, such as steel plates, wires, nails, screws, bands, etc., has been practically abandoned and that wherever possible, every surgeon of experience now prefers to use autogenous methods." These are thoughts upon which we can well ponder today. Sofield has recently voiced a very sane summary of the situation in the following words: "Metal, regardless of its degree of inertness in human tissues, is still a foreign body and every effort should be made to keep its use to a minimum."

The rehabilitation of our patients will be improved by the use of better surgical techniques, by the recognition of basic physiological truths, by the use of modern advances in anaesthesia, by the judicious employment of antibiotics, and by the realization that the surgeon can assist the natural powers of recuperation but cannot replace them.

In conclusion, therefore, may we orthopaedic surgeons, in our endless task of treating the handicapped, first, appreciate the heritage of our history; second, keep alert our scientific curiosity; and third, keep in mind the basic physiological principles of tissue reaction.

At the Second Executive Session, Dr. David M. Bosworth was inducted into office as President for the coming year. The following officers were elected for the ensuing year:

President-Elect: George O. Eaton, M.D., Baltimore, Maryland;
Vice-President: Charles Leroy Lowman, M.D., Los Angeles, California;
Treasurer: Mather Cleveland, M.D., New York, N. Y.;
Secretary: Harold A. Sofield, M.D., Chicago, Illinois.

The following were elected to membership:
Francis J. Cox, M.D., San Francisco, California
Henry B. Crawford, M.D., Rochester, New York
John S. Donaldson, M.D., Pittsburgh, Pennsylvania
J. Leonard Goldner, M.D., Durham, North Carolina
Louis A. Golstein, M.D., Rochester, New York
Emil D. W. Hauser, M.D., Chicago, Illinois
Alonzo J. Neufeld, M.D., Los Angeles, California
Richard T. Odell, M.D., St. Louis, Missouri
Herbert E. Pedersen, M.D., Detroit, Michigan
Carlo S. Scuderi, M.D., Chicago, Illinois

Elected to Honorary Membership was:
Murray M. Copeland, M.D., Washington, D. C.

The following Corresponding Members were elected:
Dr. Oscar Scaglietti, Firenze, Italy
Dr. Eivind Thomasen, Aarhus, Denmark
Mr. Philip Wiles, London, England

The next Annual Meeting of The American Orthopaedic Association will be held at The Homestead, Hot Springs, Virginia, June 24 to 27, 1957.

VIRGINIA STATE ORTHOPAEDIC SOCIETY

As Reported by WILLIAM M. DEYERLE, M.D., *Secretary-Treasurer, Richmond, Virginia*

The Virginia State Orthopaedic Society held its annual meeting on April 6 and 7, 1956 at The Hotel Roanoke in Roanoke, Virginia. The president of the Society, Dr. R. D. Butterworth of Richmond, Virginia, presided.

The Roanoke members, acting as a program committee, had prepared an excellent program.

Upper Extremity Prosthesis. DR. ROY M. HOOVER [1], MR. JOHN CRANFORD [2] (prosthetist), and MR. JOHN RAWLEY [3] (occupational therapist) described the program for the treatment of upper-extremity amputees at the Woodrow Wilson Rehabilitation Center.

It was emphasized that as a result of modern techniques of fabrication and training and as a result of the components and terminal devices which are now available, amputation stumps at any level from the wrist to the shoulder can be fitted with a prosthesis which will be of great help in rehabilitation.

The essentials in the fabrication of a modern laminated plastic prosthesis were demonstrated by the prosthetist. He explained and demonstrated the various components, such as elbow locks and elbow hinges, that are now available with the different types of terminal devices.

A number of prostheses were then demonstrated by the occupational therapist. Included among these

[1] 30½ Franklin Road, Roanoke.
[2] Fisherville.
[3] Fisherville.

were prostheses for wrist-disarticulation stumps, very short below-the-elbow stumps in children, very long above-the-elbow stumps, very short above-the-elbow stumps, and shoulder-disarticulation stumps.

Elbow Endoprosthesis. Dr. Louis P. Ripley [4] reported the use of a Vitallium endoprosthesis as the primary method of treatment in the case of a fifty-eight-year-old white male with a comminuted fracture of the distal end of the humerus. The appliance had been inserted so that it extended into the elbow joint. When last seen, after a three-year follow-up, the man had a normal range of motion, normal stability, and normal alignment with minimal loss of strength.

Spinal Anaesthesia for Operative Reduction of Fractures of the Proximal Femur in the Aged. Dr. F. Willson Daily.[5]

Osteitis Condensans Ilii. Dr. Charles B. Bray, Jr.[6], discussed osteitis condensans ilii and reviewed the etiological studies which have been made of this condition. The significance of the roentgenographic appearance of osteitis condensans ilii was re-emphasized, and comments were made on its incidence, the author citing Gillespie and Lloyd-Roberts' paper which reported an incidence of 2.2 among 760 lumbosacral spines. The clinical signs and symptoms described were the same as those reported in previous papers; and it was mentioned that low-back pain, a common symptom which is aggravated by hard work, can be somewhat relieved by conservative measures. The cases of four patients with this condition were presented; all the patients were young married females who had borne children.

Survey of Our Experience with Intramedullary Fixation in the Long Bones. Dr. Philip C. Trout [7] reported that the following general results had been obtained in the treatment of fractures of the long bones: clavicle, good; humerus, good; femur, excellent; tibia, encouraging; metacarpals and metatarsals, very good. The results in the treatment of fractures of the forearm, as yet an unsolved problem, had been variable.

Paget's Disease. Dr. John A. Martin. [8]

Surgical Problems of the Injured Hand. Dr. Richard H. Fisher [9] discussed these problems at length, illustrating his points with kodachrome slides.

Hip Surgery. Dr. James S. Speed [10], guest speaker, reviewed the results previously obtained by older methods of hip surgery and discussed at length present-day methods and results.

[4] 30½ Franklin Road, Roanoke.
[5] 371 Walnut Avenue SW, Roanoke.
[6] 203 Carlton Terrace Building, Roanoke.
[7] 1301 Franklin Road, Roanoke.
[8] 603 Medical Arts Building, Roanoke.
[9] Lewis-Gale Hospital, Roanoke.
[10] 869 Madison Avenue, Memphis, Tennessee.

OHIO ORTHOPAEDIC SOCIETY

As Reported by George S. Phalen, M.D., *Secretary-Treasurer*, Cleveland, Ohio

The Annual Meeting of the Ohio Orthopaedic Society was held in Youngstown, Ohio, on May 25 and 26, 1956. Dr. Wilbert H. McGaw, President of the Society, presided at the business meeting, and Dr. Chester Lowendorf was chairman of the clinical sessions. Dr. George S. Phalen served as Secretary-Treasurer of the Society.

Friday, May 25, 1956

Mechanical Substitute for Glutaeus Maximus. Dr. George W. Cook [1] discussed the problem of lower-extremity weakness or paralysis in conjunction with glutaeus maximus, abdominal, and back paralysis and described a mechanical device for treatment of glutaeus maximus and hamstring paralysis. This device was originally described in a paper by Dr. Daniel Riordan and Mr. Merton Miller, physiotherapist, in 1954.

Dr. Cook presented the cases of two children. One child had complete paralysis of the abdominal muscles, the glutaeus maximus, and both lower extremities but had two-plus hip flexors on the left side. At the time of the meeting this child had worn the braces for only five weeks but was able to walk across the floor

[1] 3716 Market Street, Youngstown.

using crutches. The other child had more muscular control; his case was presented to show what can be done with this type of extensor mechanism.

Internal Fixation of Fractures of Hips by Moreira Stud Bolt. Dr. S. Patton, Jr.[2], presented the results obtained by use of the Moreira stud bolt in the fixation of 349 fractured hips during the past five years. In Dr. Patton's procedure two wires were used to maintain the position of the head of the femur as the bolt was inserted. The Moreira bolt is simple to use, easy to insert, and it impacts and holds the fragments in apposition. It causes less trauma during application and provides better control than do other appliances. Dr. Patton reported that the incidence of union following its use was almost 50 per cent.

Measurement of the Optical Density of Serum as a Screening Method for Cancer. Dr. James A. Quinn[3], Mr. Stanley A. Katz[4], and Dr. Arthur E. Rappoport[5] reported that the determination of the optical density of serum by means of the Beckman spectrophotometer (DK-2 and DU) has revealed significant differences between the sera of persons having cancer and those of normal persons or of patients with non-cancerous diseases. There was a distinct reduction in the optical density of the sera in patients with cancer as compared to the density found in the other two groups.

In a series of 5,377 patients, 578 had cancer, 2,836 were normal, and 1,963 had diseases other than cancer. According to the criteria for interpretation of the test, the results in 88.4 per cent of the patients with cancer were true-positive and the results in 11.6 per cent were false-negative. Of the results in normal persons, 97.7 per cent were true-negative while 2.3 per cent were false-positive. In the group with diseases other than cancer, 84.8 per cent of the reactions were true-negative, while 15.2 per cent were false-positive. The false-negative results were chiefly encountered in patients with terminal or extremely advanced cancer. The greatest percentage of false-positive results were observed in patients with acute and chronic inflammations caused by disease other than cancer.

Avulsion of the Distal Biceps Tendon. Dr. Robert M. Foster[6] presented three previously unreported cases of rupture or avulsion of the biceps tendon at its distal insertion. In one patient the tendon had been sutured to the bicipital tuberosity; the other two patients had been treated by fixation of the tendon to the brachialis. In all three the functional result was excellent.

Closed Treatment of Elbow Fractures in Children. Dr. W. D. McElroy[7] reported that, in children, dicondylar fractures of the lower end of the humerus are more serious than supracondylar fractures. At times it is extremely difficult to obtain reduction of these fractures, and the results are not always satisfactory. Rotation of the knifelike edge of the distal fragment, even when it is minimal, may cause loss of the carrying angle, particularly if the inner condyle has been rotated backward and the external condyle has been rotated slightly forward.

Tomography of Sternoclavicular Joint. Dr. E. C. Baker[8] reported that in the diagnosis of conditions involving the region immediately surrounding the sternoclavicular joint, tomography has proved of greater value than standard types of roentgenography. Examples of tomograms were presented.

Saturday, May 26, 1956

The Saturday morning clinical session was held in the auditorium of the St. Elizabeth Hospital.

Open Reduction of Elbows in Adults. Dr. J. Sofranec[9] reported four cases in which comminuted fractures about the elbow had been treated by open reduction and internal fixation. Two of the four patients had had comminuted fracture of the ulna with associated fracture of the head of the radius. In these cases the fragments had been fixed by means of Leinbach contour intramedullary screws; in one of these cases a screw had bent, and there had been delayed union of the fragments of the olecranon. In the third case there had been fracture of the proximal third of the ulna associated with fracture of the head of the radius; this patient had been treated by excision of the radial head and fixation of the fragments by means of an intramedullary pin and cross screws. The fourth fracture had been a "sideswipe" fracture of the elbow with extreme comminution of all bones about the elbow; it had been treated by means of wire and chromic sutures. The anatomical result was poor, but the functional result was good.

[2] 5532 Mahoning, Youngstown.
[3] 4011 Arden, Youngstown.
[4] 2355 Goleta, Youngstown.
[5] 48 Ridgewood Drive, Youngstown.
[6] 402 Oak Hill, Youngstown.
[7] 3718 Market Street, Youngstown.
[8] Oak Hill and Francis, Youngstown.
[9] 710 Wick Building, Youngstown.

Ultrasound in Orthopaedics. Dr. Ivan C. Smith [10] presented a short history of ultrasound as a means of treatment for skin ulcers, muscle pains, and arthritis. He discussed the physical principles involved in the use of ultrasound and the application of these principles in both industry and medicine. He felt that in the treatment of such conditions as bursitis, periarthritis, tenosynovitis, myositis, myofascitis, arthritis, and neuroma in amputation stumps, ultrasound therapy has achieved a measure of success; and he concluded that while the results have not usually been as dramatic as some reports would indicate, they have been generally good and justify the use of this therapy in appropriate conditions.

Use of Staples Other Than for Epiphyseal Arrests. Dr. T. Kernan Golden [11] stated that in numerous conditions the use of stainless-steel staples to obtain bone fixation offers an advantage over other means. Among the conditions which these staples have been used to treat are fracture of the femoral neck in a child; posterior marginal tibial fractures; condylar fractures of the humerus in children; and certain unstable tarsal fractures, dislocations, and arthrodeses. These staples generally are placed in a superficial location and usually are removed after they have served their purpose.

Anaesthesia Problems in the Aged. Dr. Anthony J. Bayuk [12] stated that the average life expectancy of the male is 64.5 years and that of the female is 69.8 years. The increase in longevity in recent years complicates the use of anaesthesia because of the effects of "pure aging" and because of the debilitating diseases which occur in old age. In preoperative preparation the aged patient's condition must be carefully evaluated and all reversible pathological states, such as anaemia and vitamin deficiency, must be corrected. A higher death rate is associated with low levels of vitamin A, niacin, and ascorbic acid, and many so-called unexplainable deaths are the result of pre-existing conditions of chronic shock. The aged patient tolerates poorly the opiates, barbiturates, and hyoscine, but benadryl may be used safely as a sedative and anti-fibrillary drug. The general approach should be conservative, and overdosage should be avoided. Local infiltration is not a foolproof technique, and when it is used, the total dose should be recorded in order to avoid the development of myocardial depression due to overdosage of procaine.

Roentgen Findings in Some Unusual and Interesting Conditions Encountered in the Cervical Spine. Dr. Raymond J. Scheetz [13] presented a group of roentgenograms showing lesions of the cervical spine. Among the lesions demonstrated were several interesting or unusual anomalies, including total absence of the odontoid process, atloido-occipital synostosis, extremely long spinous processes, spondylolisthesis, block vertebrae, Klippel-Feil deformity, and Sprengel's deformity.

The roentgenographic findings in two cases of neoplastic disease—neurofibroma and chordoma—were also demonstrated.

1. Some Tendon Transplantations in Poliomyelitis. 2. Congenital Genu Recurvatum. Dr. C. S Lowendorf [14] presented movies showing the preoperative condition of four patients in whom tendon transplants had been performed in order to correct paralytic deformities. In one of these four patients the tensor fasciae latae had been transplanted medially to correct adductor paralysis; in another the tensor fasciae latae had been transplanted backward to correct gluteal weakness. In the other two cases a trapezius transplant to correct a weak deltoid and bilateral transplants of the hamstrings to the patella had been done. Three cases of genu recurvatum in which the synovial attachments were abnormal were also presented.

At a business meeting, ten new members of the Society were elected:

Dr. Paul R. Miller, Columbus;
Dr. Harold Snedden, Sandusky;
Dr. Thomas J. Radley, Cincinnati;
Dr. William B. Mikita, Steubenville;
Dr. H. C. Messenger, Dayton;
Dr. Robert T. Gallagher, Cincinnati;
Dr. Myron Pardee, Lakewood;
Dr. Paul H. Curtiss, Cleveland;
Dr. Thomas H. Brown, Toledo;
Dr. James G. Roberts, Akron.

The new officers of the Society are:

President: Dr. H. P. Worstell, Columbus;
President-Elect: Dr. Robert Perlman, Cleveland;
Secretary-Treasurer: Dr. Charles Herndon, Cleveland.

[10] Home Savings and Loan Building, Youngstown.
[11] Central Tower Building, Youngstown.
[12] 107 Jenette Drive, Youngstown.
[13] St. Elizabeth Hospital, Youngstown.
[14] Home Savings and Loan Building, Youngstown.

NORTHEAST ORTHOPAEDIC CLUB

The Annual Meeting of the Northeast Orthopaedic Club was held at the University of Virginia Hospital, Charlottesville, Virginia, on May 3, 1956. In opening the meeting, Dr. J. H. Allan outlined briefly the history of the University of Virginia, the School of Medicine, and the Department of Orthopaedics.

The following papers were presented.

Factors Influencing the Rate of Union in Fractures of the Tibia. Dr. E. D. Vere Nicoll [1].

Leukaemia. Dr. Paul S. Derian [2] presented a survey of 116 cases of leukaemia (eight-six adults and thirty children) in order to evaluate the bone and joint symptoms and the osseous lesions.

Supracondylar Fractures of the Humerus in Children. Dr. C. Randolph Borzilleri [3].

The Anatomy of Bone Cysts. Dr. Robert G. Kindred [4] presented a preliminary report on a study being undertaken at the Armed Forces Institute of Pathology on the anatomy of bone cysts.

Expert Testimony. Dr. Charles J. Frankel [5] discussed the roll of the medical expert in trials, personal-injury cases, and malpractice suits.

Upper Extremity Prosthetics. Dr. Roy M. Hoover [6], Medical Director of the Woodrow Wilson Rehabilitation Center, Fisherville, Virginia, demonstrated recent advances in prostheses for the upper extremity.

Malignant Bone Tumors. Dr. R. Warner Wood, Jr. [7], presented a series of cases of bone tumors. Included in this series were several cases of malignant giant-cell tumors, a case of Ollier's multiple enchondromatosis with chondrosarcoma, a case of multiple exostoses with chondrosarcoma, and a case of osteogenic sarcoma of the distal phalanx of the index finger.

Fractures of the Neck of the Femur in the Mental Patient. Dr. E. D. Vere Nicoll [1] and Dr. Bennett Caughran [8] discussed the difficulty of treating fractures of the neck of the femur in mental patients. Twenty-two prosthetic arthroplasties of the hip had been done and had been found to give much better results than the Smith-Petersen nailing operation.

[1] University of Virginia Hospital, Charlottesville, Virginia.
[2] University of Virginia Hospital, Charlottesville, Virginia.
[3] 292 Niagara Street, Buffalo, New York.
[4] Armed Forces Institute of Pathology, Washington, D. C.
[5] University of Virginia Hospital, Charlottesville, Virginia.
[6] 305½ Franklin Road, Roanoke, Virginia.
[7] 1113 Amsterdam Avenue, New York, N. Y.
[8] University of Virginia Hospital, Charlottesville, Virginia.

TEXAS ORTHOPAEDIC ASSOCIATION

As Reported by Margaret Watkins, M.D., *Secretary-Treasurer*, Dallas, Texas

The Texas Orthopaedic Association held its Annual Meeting on April 23, 1956, at the time of the State Medical Meeting in Galveston, Texas. The meeting was attended by fifty members and by about an equal number of guests.

Nineteen new men were elected to membership.

The following men were elected to office:

President: Dr. John J. Hinchey, San Antonio;
Vice-President: Dr. Lawrence Griffin, Austin;
Secretary-Treasurer: Dr. Margaret Watkins, Dallas.

Dr. Rex L. Diveley of Kansas City, Missouri, was elected to Honorary Membership.

Athletic Injuries to the Knee Joint. Dr. Rex J. Howard [1].

Skeletal Changes Noted in a Series of Sickle Cell Cases. Dr. Richard W. Leong [2] reported that skeletal changes in sickle-cell anaemia are the result of two main processes: bone-marrow hyperplasia and circulatory stasis and thrombosis. Repeated intercurrent infections may also be a contributing factor. In young children the skeletal changes are predominantly the result of marrow hyperplasia. In older children and in adults, the skeletal picture is a composite of marrow hyperplasia, bone necrosis, and bone sclerosis.

Dr. Leong reported that in twenty-four of the thirty-two sickle-cell cases at the Veterans Hospital, Houston, interviews and skeletal roentgenographic examinations had been carried out. In 65 per cent of these cases advanced skeletal changes had been found.

There were nineteen pediatric sickle-cell cases at Jefferson Davis Hospital. Of the seventeen cases in which bone roentgenograms had been available, 23.5 per cent had showed advanced bone changes.

The author presented twenty-seven illustrations, including roentgenograms and photomicrographs, demonstrating the changes noted in patients with sickle-cell disease. Roentgenographic illustrations of the orthopaedic conditions which sickle-cell disease often simulates were also presented.

Sickle-cell disease simulates many diseases, including osteomyelitis, osteitis deformans, osteopetrosis, osteoblastic metastatic neoplasm, Perthes' disease, caisson disease, aseptic necrosis of the hip following injury, rheumatoid arthritis, rheumatic fever, osteochondritis dissecans, syphilis, Gaucher's disease, enchondroma, lumbosacral diseases, radiation necrosis, osteopoikilosis, chronic myelogenous leukaemia, fluorosis, and neuromuscular conditions.

A survey of Negro orthopaedic patients at the Veterans Hospital in Houston is being conducted currently to determine the incidence of sickle-cell disease and the frequency with which it simulates orthopaedic diseases.

The Post-Poliomyelitis Calcaneo-Valgus Foot. Dr. Louis W. Breck [3].

Pitfalls in Spinal Surgery. Dr. Paul C. Williams [4].

Surgery of the Hip. Dr. T. Wiley Hodges [5].

Pollicization. ***Surgical Construction of a Thumb from the Index Finger.*** Dr. R. A. Murray [6].

[1] 930 Fifth Avenue, Forth Worth.
[2] Baylor University College of Medicine, Houston.
[3] 520 Montana Street, El Paso.
[4] 3607 Gaston Avenue, Dallas.
[5] 3707 Gaston Avenue, Dallas.
[6] 1110 North Eighth Street, Temple.

CORRECTION

In the summary of the paper by Dr. Fritz Teal, *Congenital Dysplasia of the Upper End of the Femur*, presented at the Annual Meeting of the Association of Bone and Joint Surgeons, an error appears on page 946, paragraph 8, line 5. For the sentence to be correct, the line must read: "at the age of eight of nine in order that the patient would have a stable hip to which an artificial limb could be fitted much more to advantage" instead of "at the age of eight or nine in order that he might later insert a prosthesis".

News Notes

The next Annual Meeting of **The American Orthopaedic Association** will be held at The Homestead, Hot Springs, Virginia, June 24 to June 27, 1957.

The next Annual Meeting of **The American Academy of Orthopaedic Surgeons** will be held in Chicago, Illinois, January 26 to 31, 1957.

The Twelfth Annual Meeting of the **American Society for Surgery of the Hand** will be held at the Palmer House, Chicago, Illinois, on Friday, January 25, 1957, under the Presidency of Dr. L. D. Howard, Jr. The tentative program is as follows:

Restoration of Finger Function by Tenodesis in the Hand Paralyzed by Poliomyelitis. Dr. J. B. Wray and Dr. C. E. Irwin, Warm Springs, Georgia;

Tendon Grafts in Children. Dr. Lee Milford, Memphis, Tennessee;

Flexor Tendon Injuries of the Fingers and Thumb. Dr. Albert Van't Hof, Grand Rapids, Michigan;

Mallet Finger. Classification and Methods of Treatment. Dr. Donald R. Pratt, San Francisco, California;

The Problem of Collagen Diseases. Dr. William E. Ehrich, Philadelphia, Pennsylvania;

The Extensor Mechanism (a motion picture). Dr. Joseph Markee, Durham, North Carolina;

Fingernails. Infection, Diseases, and Pathology. Dr. Cleveland White, Chicago, Illinois;

Sporotrichosis. Report of Thirty-seven Cases in the Upper Extremity. Dr. Mark Coventry, Rochester, Minnesota;

Electrical Burns of the Upper Extremity. Dr. G. Kenneth Lewis, Chicago, Illinois;

The Principles of Reconstruction of the Upper Extremity Paralyzed by Poliomyelitis. Dr. Edwin R. Schottstaedt, Dr. Loren Larsen, and Dr. Frederic Bost, San Francisco, California.

Recent Developments in Hand and Forearm Prostheses. Dr. Rufus Alldredge, New Orleans, Louisiana.

EXCHANGE FELLOWSHIPS

The Exchange Fellowships Committee of The American Orthopaedic Association invites application from American orthopaedic surgeons for the four fellowships to visit Great Britain in the spring of 1957. All applications must be in the hands of the Committee by December 1, 1956; any submitted after that date cannot be considered. General requirements for each applicant are:

1. American citizenship;
2. Successful completion of Part II of the American Board of Orthopaedic Surgery Examinations;
3. The applicant must be under forty years of age as of December 1, 1956.

Application forms and other details of application will be furnished upon written request to the Committee Chairman, Dr. J. Neill Garber, 806 Hume Mansur Building, Indianapolis 4, Indiana.

The effectiveness of current public health programs on international, national, state, and local levels will be analyzed in the five-day Eighty-fourth Annual Meeting of the **American Public Health Association** and meetings of forty related organizations in Convention Hall, Atlantic City, New Jersey, November 12 to 16, 1956. Nearly 400 papers will be given. Each of the Association's fourteen specialty sections will hold sessions concerned with the latest research and other current aspects of its particular field. President is Dr. Ira V. Hiscock, Chairman of the Department of Public Health, Yale University.

The Annual Meeting of the **American Academy for Cerebral Palsy** will be held at the Congress Hotel, Chicago, Illinois, November 17, 18, 19, 1956. Invitations may be had by writing to the Secretary, Dr. Robert A. Knight, Campbell Clinic, 869 Madison Avenue, Memphis, Tennessee.

The **National Foundation for Infantile Paralysis** announces fellowships for orthopaedic surgeons to provide advanced training in teaching or research in orthopaedics. Only physicians who have completed the requirements for certification by the American Board of Orthopaedic Surgery or who have equivalent training are eligible for the awards. The age limit is thirty-six. For further information interested persons should write to Professional Education Division, National Foundation for Infantile Paralysis, 120 Broadway, New York 5, N. Y.

The Ninth **International Congress on Rheumatic Diseases** will be held at Toronto, Ontario, Canada, from June 23 to 28, 1957, under the auspices of the Canadian Rheumatism Association.

The Program Committee invites contributions to the scientific program of the Congress and is anxious to receive reports on current clinical or basic research dealing with any aspect of the rheumatic diseases.

Those offering papers for consideration should submit a 200 to 300 word abstract not later than January 1, 1957. Abstracts should be submitted in triplicate in the language in which the paper is to be read. If an abstract is submitted in a language other than English, it will be helpful, although not essential, if it can be accompanied by an English translation.

All correspondence should be directed to: The Ninth International Congress on Rheumatic Diseases, Post Office Box 237, Terminal "A", Toronto, Ontario, Canada.

The Seventh Congress of the **Pan-Pacific Surgical Association** will be held in Honolulu, Hawaii, November 14 to 22, 1957. Further information and brochures may be obtained by writing to Dr. F. J. Pinkerton, Director General of the Pan-Pacific Surgical Association, Room 230, Young Building, Honolulu, Hawaii.

Book Reviews

AUTORADIOGRAPHY IN BIOLOGY AND MEDICINE. George A. Boyd. New York, Academic Press, Inc., 1955. $8.80.

The term "autoradiography" signifies the production of an image on a photographic emulsion by radiation from the object itself. The image can be studied by the naked eye or with the help of a microscope. When the image is studied with reference to the spatial relations of the object containing the radioactive atoms, it can give information concerning the sites of labeled atoms or molecules. The autoradiographic technique is almost as old as the x-ray technique; however, it was not until artificially produced radioactive isotopes became readily available that the method achieved importance for biological investigations.

The author, George A. Boyd, has pointed out that autoradiography as used in biology and medicine is a fine art based on science. The first part of the book is devoted to a thorough discussion of the theory of autoradiography with chapters on the photographic process, comparisons of different types of photographic emulsions, on resolution, and on estimates of doses and exposure time. The importance of the chapter on sources of error has been emphasized in a subtle way by an autoradiograph on the jacket of the volume which is actually an artifact! The second part of the book deals with special techniques such as producing autoradiographs of non-flat surfaces (for example, wrapping a radioactive bone with photographic emulsion), and of flat surfaces (for example, placing the emulsion in contact with a section of a radioactive bone or in contact with microscopic sections). A special chapter is devoted to techniques for preparing histological sections of undecalcified bone and teeth.

The bibliography is in itself an achievement, complete through 1953, and is unusually well systematized.

The book as a whole makes pleasant reading although, or perhaps because, it is packed with precise information. The style is clear. The book should be of great help both to advanced workers in the field of autoradiography and to those who contemplate using the technique. For those who do not, it will prove helpful in understanding papers on the subject. For persons working in the field of bone morphology and physiology the book will be of especial interest since the author has devoted a large share of his time (and his book) to autoradiography of bone.

It seems almost unfair to ask for anything more in this nearly perfect book. It would have been interesting, however, to learn the author's views on the possibility of objective quantitative interpretation of autoradiographs, for it is exactly here that this technique has its most serious limitations when compared with other methods of isotope assay.

Robert D. Ray, M.D.
Goran C. H. Bauer, M.D.

THE BIOCHEMISTRY AND PHYSIOLOGY OF BONE. Edited by Geoffrey H. Bourne. New York, Academic Press, Inc., 1956. $20.00.

In the preface to this book, the compiler, G. H. Bourne, says: "In the last twenty-five years there has been a rapid development of new techniques and enthusiasm in their application to bone studies, a store of new knowledge has been accumulated about structure and function of bone and a growing appreciation of the skeleton as a plastic actively metabolizing tissue. Papers dealing with these and other aspects of bone are published in an astonishingly wide range of journals throughout the world. The present treatise is the outgrowth of a belief that the time had come to collect these diverse studies into an integrated volume. Its comprehensiveness should make it of interest to many experts, and in particular to histologists, to anatomists, to specialists in orthopaedics and pediatrics, and to dentists; in addition, I hope that many biologists, physiologists, bio-chemists, and pathologists will find a great deal of interest and value to them between its covers."

This hope, I am sure, will soon be realized since the book achieves two ends which will insure its popularity; first, an over-all summary and reference source for recent work in diverse fields, and second, a working bibliography for those interested in pursuing in more detail any of the subjects covered. The book has twenty-four chapters, no single author having contributed more than two. Because of this, there is much variability in style, in conciseness, in the indulgence in speculation, and in the degree of concentration of each author on his own contribution. For the most part, the authors have done their job well, each one writing in the area of his active research. There is just enough overlap in the coverage of the subject that no topic of consequence is omitted and yet, repetition of material is held to the minimum.

The chapters I may single out for special commendation are those on mineral salts by Carlstrom and Engstrom, on the osteoclast by Hancox, on the parathyroid by McLean, and on radiation by Vaughan. The chapters on the organic matrix by Eastoe and on collagen by Rouiller are also outstanding summaries of fields of knowledge opened up by newer technical methods. Some of the other chapters are characterized by more classical presentations of material, and therefore do not present the attraction of novelty. These pertain to vitamin A and C, to steroid and pituitary hormones, and to embryology and histology. It is regrettable that the chapter on vitamin D has not been as inclusive of the recent isotope work as it might be. This, indeed, is a small criticism in the light of the broad general competence that the book demonstrates. Other chapters not previously mentioned pertain to mechanics, phosphatase, citric acid, tissue culture, bone repair, autoradiography, growth, ground substance, and pathological calcification.

This book should prove a milestone in the education of all orthopaedists, since nearly every phase of the normal physiology of bone and its investigation has been covered. The text is easily readable and, for the most part, interestingly written. The figures leave something to be desired, however, both in quality and quantity, and the high price of the volume must be decried.

Jonathan Cohen, M.D.

SURGERY OF THE HAND. Ed. 3. Sterling Bunnell, M.D. Philadelphia, J. B. Lippincott Company, 1956. $22.50.

Advances in hand surgery have been numerous and important during the past few years. The compilation of a third edition has permitted Dr. Bunnell to include in his great *Surgery of the Hand* an account of many of these developments. This edition has also enabled him to treat many of the subjects in a manner even more thoroughgoing than before.

First published in 1944 and appearing again in 1948 in a much enlarged and thoroughly up-to-date edition, Dr. Bunnell's *Surgery of the Hand* is recognized throughout the world as a truly great contribution to surgery. It is indispensable. Few surgical treatises have been so widely studied and are so stimulating. The labor of few surgeons has been so successful in raising to such high standards the quality of surgery in their field.

In this edition the design of the book again remains unchanged, the style is the same, and there is the same thoroughgoing treatment of each subject. Expanded is the chapter on Infections of the Hand so as to include a section devoted to antibiotics. A short description of cross-finger flaps has been added to the chapter on Skin and Flexion Contractures. The section on Postoperative Treatment After Repair of Tendons has been enlarged to include new techniques, especially new timing, in exercise therapy. New methods of dealing with contraction and paralysis of intrinsic muscles have been described in the chapter devoted to this subject. The important alterations in the physiological processes in burns are discussed in the light of newer knowledge of the subject, and the section devoted to the local treatment of burns has been brought up to date. Newer techniques in elbowplasty have been included in the chapter, The Arm in Its Relation to the Hand, several new muscle transfers being described. There is a short description of the so-called seal finger.

Two hundred and seventy-seven new illustrations have been added.

Those concerned with the teaching of surgery and with the surgical treatment of the hand will wish to have this book in their libraries.

William A. Rogers, M.D.

VASCULAR SURGERY IN WORLD WAR II. Edited by Daniel C. Elkin, M.D., and Michael E. DeBakey, M.D. Washington Office of the Surgeon General, Department of The Army, 1955. $4.25.

In the Medical Department's series, *Surgery in World War II*, the volume on Vascular Surgery presents an excellent summary of the experiences of the Medical Corps. This 464-page volume is a striking contrast to the single paragraph given to vascular surgery following the first World War.

Various authors have contributed the individual chapters. There is an excellent section on the clinical evaluation of the arterial circulation of the extremities. The importance of adequate exploration of wounds which might involve arteries and the methods of repair is stressed. This approach will avoid serious delayed hemorrhage and later aneurysm formation, and will save many limbs.

The use of vein grafts is described in a small series of patients. Since the War much more progress in the field of reconstructing arteries has been made, making this section somewhat outdated, but of historical interest.

Volkmann's ischaemic contracture due to arterial occlusion is discussed and the importance of early fasciotomy is emphasized.

Much of the volume is devoted to the description of the large series of arterial aneurysms and arteriovenous aneurysms which were treated with brilliant results (four deaths in 801 operations). The physiological changes produced by these situations are discussed in detail. The various exposures worked out to reach the more inaccessible of these are most interesting and instructive.

Brief mention is made of the use of anticoagulants in these cases, and the authors conclude that there is no proof of their value. The Army's small experience with Raynaud's Disease, Buerger's Disease, and arteriosclerosis is reviewed.

This volume is full of useful information on the application of one of the most recently developed branches of surgery to the problems incurred in war time. The principles of direct surgery on injured arteries are well stated and much can be learned that is applicable to peace-time traumatic surgery.

Frank C. Wheelock, Jr., M.D.

CHRISTOPHER'S MINOR SURGERY. Ed. 7. Edited by Alton Ochsner, M.D., F.A.C.S., and Michael E. DeBakey, M.D., F.A.C.S. Philadelphia, W. B. Saunders Co., 1955.

Christopher's Minor Surgery has been thoroughly revised and indeed rewritten in the Seventh Edition under the editorship of Dr. Ochsner and Dr. DeBakey. The new work is the effort of many authors, all of whom have been members of the Editors' departments of surgery. In this way there is a certain unity of approach, and repetition, a common failing of multiple authorship, is avoided. Quite properly the Editors preface the volume with an apology for the term "minor surgery", but excuse its use because of custom and lack of a better designation.

Since the book was written primarily with the junior surgical resident in mind, the authors begin with a useful section devoted to equipment, general consideration of the extent and conduct of minor surgery, dressings, and anaesthesia. There is an excellent chapter, which will probably not be read by many, on the surgical resident's training, attitudes, and responsibilities.

The balance of the book is divided by anatomical systems: skin and subcutaneous tissues, musculoskeletal system, alimentary tract, peripheral-vascular diseases, genito-urinary system, the head (eye, ear, nose and throat), and the nervous system. In the treatment of these systems, the authors have taken the proper course, extending their coverage to a fairly complete review of many lesions which are manifest externally, although first seen in the ambulatory patient. The presentation is in most cases succinct with sufficient information about the pathology and physiology. In those cases where the problem is primarily one for ambulatory care, the sections on therapy and procedures are sufficiently complete for use as a safe guide. Thus, the section on musculoskeletal injuries and deformities is an adequate review of the most frequently seen problems, with the larger portion of the text devoted to conditions which can be handled on an ambulatory basis.

The surgical resident in his out-patient work, and the surgeon and general practitioner in his office library will find this book a handy source of specific information on a host of lesions described elsewhere in scattered places, often incompletely.

Hermes C. Grillo, M.D.

SURGERY (Z-PLASTY) IN PROGRESS: Color photographs on following page illustrate 3 significant steps.

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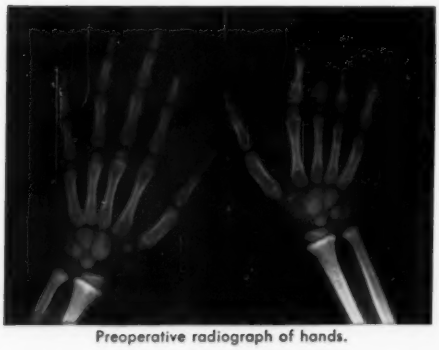

Preoperative radiograph of hands.

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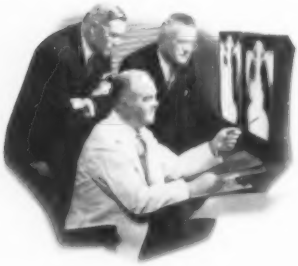
1. Congenital constricting uterine bands, palmar view.

2. Exposure of digital nerve through Z-plasty.

3. Suturing transposed Z-plasty flaps.

Note: Z-plasty is a plastic operation for the relaxation of contractures caused by congenital uterine bands (case illustrated) or scar tissue growth. In this surgery, a Z-shaped incision is made over the contracture and the triangular flaps rotated so that their apices cross the line of contracture.



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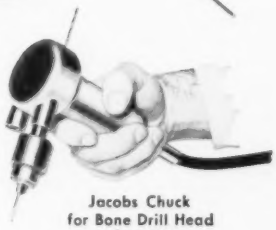

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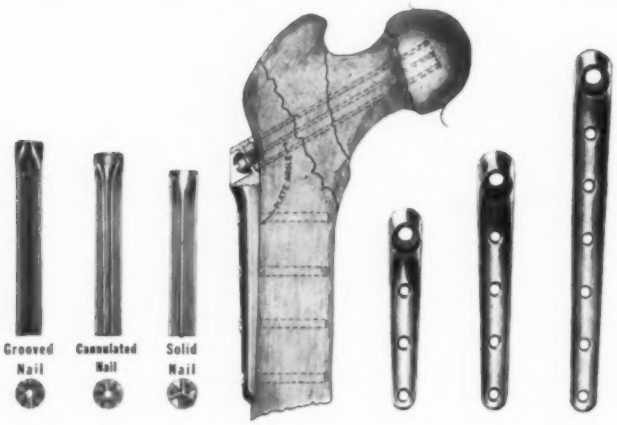

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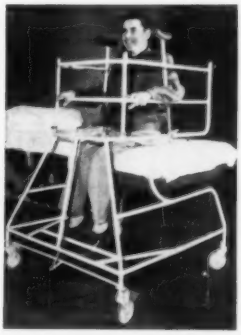

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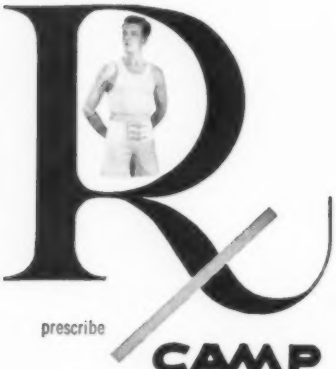

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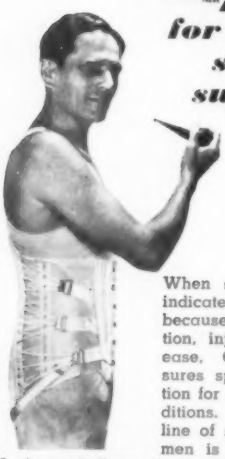

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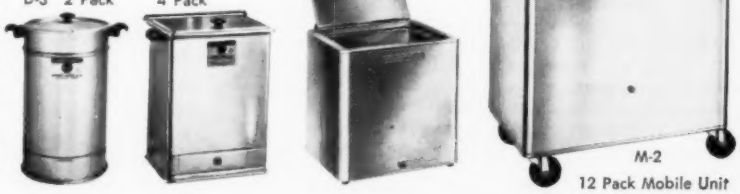

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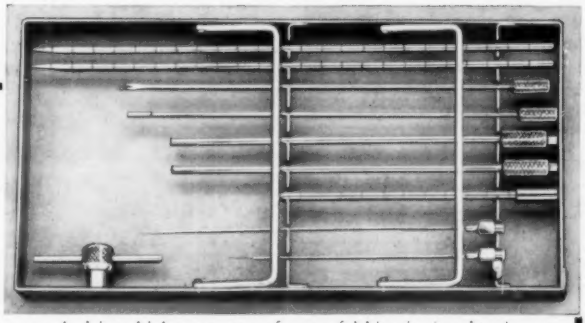

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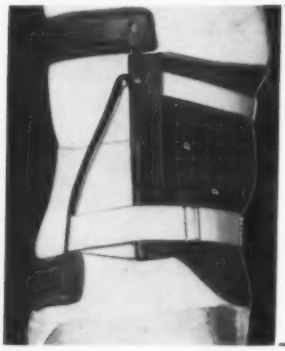

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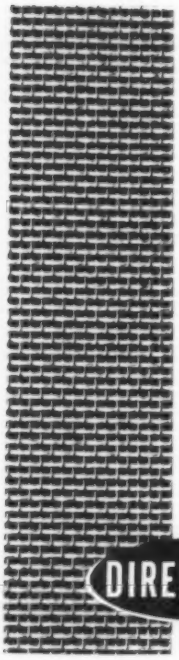

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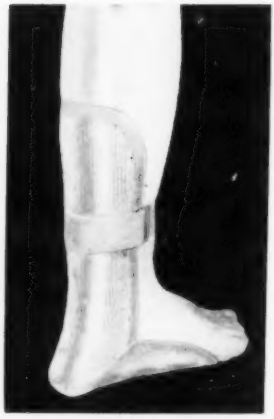

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	PAGE
Airefoam Bedding Company	48
C. H. Alden Shoe Company	12
Alhambra Clinic	54
Astra Pharmaceutical Products, Inc.	13
Austenal, Inc.	27, 41
Ayerst Laboratories	36, 46
Bauer & Black, Division of The Kendall Company	19, 58
The Berivon Company	4
Boston Artificial Limb Co., Inc.	52
Bowen & Company, Inc.	49
S. H. Camp and Company	46
Chattanooga Pharmacal Company, Inc.	51
G. W. Chesbrough, Inc.	48
Gilbert Hyde Chick Company	31
C. & J. Clark Limited	52
Codman & Shurtleff, Inc.	20
DePuy Manufacturing Co., Inc.	22
Direkt-Form Corporation	56
Eastman Kodak Company	39, 40
J. Edwards Shoe Company	21
Elgin Exercise Appliance Company	28
Fillauer Surgical Supplies, Inc.	57
Florida Brace Corporation	44
Freeman Manufacturing Company	57
S. R. Gittens	54
The Hack Shoe Company	45
J. E. Hanger, Inc.	26
Hausted Manufacturing Company	8
Herbst Shoe Manufacturing Company	34
House of Bidwell, Inc.	55
Johnson & Johnson	37, 38
Kleistone Rubber Company	18
J. B. Lippincott Company	50
McNeil Laboratories, Inc.	16, 17
M. J. Markell Shoe Company, Inc.	55
Medical Research Specialties	30
Miller Brace Co.	54
Minnesota Orthopedic Services	50
V. Mueller & Co.	53
Merck Sharp & Dohme, Division of Merck & Co., Inc.	5, 23
Orthopedic Equipment Company	24
Orthopedic Frame Company	42, 43
J. A. Preston Corp.	54
Price Flller Machine & Mfg. Co.	44
Professional Products Co.	55
Rajowalt Co.	52
Richards Manufacturing Company	10, 11
Ries Corporation	52
Roberts, Johnson, & Rand, Division of International Shoe Co.	25
I. Sabel, Inc.	47
Schering Corporation	9
Chas. A. Schmidt Surg. Inst. Co.	32
The Selby Shoe Company	29
Smith & Nephew, Inc.	35
Tractolator Company	53
Truform Anatomical Supports	14
The United Limb and Brace Co., Inc.	50
United States Manufacturing Company	33
H. Weniger	51
Wright Manufacturing Company	15
Louis Yellin, Inc.	55
Zimmer Manufacturing Co.	6, 7

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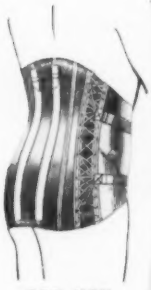

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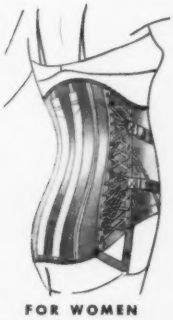

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